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RARE ELEMENT PROSPECTING IN PEGMATITES.

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ABSTRACT.

The search for rare elements in pegmatites can be facilitated by applying chemical, physical, and mineralogical associations to the selection of a suitable test mineral which then may be expected to give clues as to the presence or absence of the rare element in the pegmatite. The characteristics and functions of certain test minerals are described.

The rare earths, columbium and tantalum, vanadium, and the rare alkalies are discussed with these points in mind.

INTRODUCTION.

IT is the purpose of this paper to point out an approach to the problem of prospecting for the rarer elements. This approach is based on the belief that the minor constituents of the relatively common, but not too common, minerals of a pegmatite will give clues as to the nature and mode of occurrence of the rare elements in the pegmatite and its geological associations. These test minerals must be of such nature as to afford a ready verification of the presence or absence of the element sought, and they must themselves be present in sufficient quantity to be easily found.

ASSOCIATIONS IN PEGMATITES.

For the purpose at hand, two kinds of chemical associations may be recognized in pegmatites: (1) those based on the similarity of certain chemical and physical properties of the elements, and (2) those based on the pressure-temperature-concentration relationships governing the order of crystallization of rock and pegmatite minerals.

Chemical and Physical Similarities. The grouping of the elements as presented in the Periodic Table of the atoms serves as a basis for one kind of similarity. For example, the rare earth elements are so much alike in their chemical properties that it is natural to assume that wherever one is found the others will also be found in greater or less amount. The alkalies are another obvious example. In general, it may be said that this type of association may be expected among those groups of elements that are chemically similar, *e.g.*, the alkalies, alkaline earths, rare earths, zirconium and hafnium, columbium and tantalum, etc.

A second kind of similarity between the elements is due to the relative sizes of the ions. During the formation of crystalline substances through the precipitation of ions, the developing crystal lattice acts as a sorting agent and allows only those ions of a limited range in size to take part as structural units in the lattice. Those foreign ions which have ionic radii (the radii of the atoms after they have become charged by ionization) closest to that of the ions forming the crystal lattice have preference over other foreign ions, but if the foreign ions have the same size but different valences, the one having a valence nearest to that of the ions forming the crystal lattice will have preference. As an illustration, consider the crystallization of rare earth magnesium nitrates ($2R(NO_3)_3.3Mg(NO_3)_2.24H_2O$) from an aqueous solution containing lanthanum, praseodymium, and neodymium. The first crystals to form will be enriched in lanthanum, since lanthanum magnesium nitrate is the least soluble constituent. Aside from the fact that neodymium magnesium nitrate is slightly more soluble than the other two salts, the lanthanum magnesium nitrate crystals will tend to be contaminated with more praseodymium than neodymium because the ionic radius of praseodymium is closer to that of lanthanum than is the ionic radius of neodymium (ionic radii: $La^{+3} = 1.00$ Å, $Pr^{+3} = 0.91$ Å, $Nd^{+3} = 0.90$ Å).

Order of Crystallization. A second type of association is based on the physical chemistry of igneous rock formation. The location of the element in the form of its mineral depends upon the original composition of the parent magma, and the pressure-tem-

perature-concentration relationships which determine the sequence of mineral crystallization in the pegmatite and its associated rocks. Certain elements not found in pegmatites to any great extent are sometimes found in other bodies which are associated with pegmatites but which originated under different conditions. Specifically, one should consider the whole range of deuteric, endomorphic, and contact metamorphism, and other processes involving the "fugitive" elements of magmatic origin.

Geological Associations. Goldschmidt's mineralogical phase rule admits one additional potential mineral for every element added to a system. As applied to the rare elements, this means that each rare element may occur in its own particular mineral. In certain cases the rare mineral possible would not be recognized without specific search for it, but with definite search it might be found. For statements of facts regarding mineralogical occurrences and associations, the present writers rely upon the works of Fersmann,[1] Gevers,[2] Landes,[3] and Niggli;[4] these authors agree essentially as to the conditions and order of development of pegmatite minerals, and they represent between them the larger share of professional opinion.

The interpretation of geological associations for the location of the rarer elements in the pegmatite requires that two factors be borne in mind: (1) the nature of the element as compared with other elements or groups of elements, and (2) the possibility that the element, under specific conditions, may form stable minerals conspicuously different from those characteristic of the group to which it normally belongs. In studying the first of these factors, reference should be made to the fundamental work of Goldschmidt on the ionic radii of the elements.[5] Reference must always be

[1] Fersmann, A. E.: Über die geochemisch-genetische klassifikation der granit-pegmatite. Mineral. und Petrog. Mitteilungen, 41: 64, 200, 1931.

[2] Gevers, T. W.: The pegmatite area south of the Orange River in Namaqualand. S. Africa Geol. Surv. Mem. 30, 1937.

[3] Landes, K. K.: Origin and classification of pegmatites. Am. Min. 18: 33, 95, 1933.

[4] Niggli, P.: Lehrbuch der Mineralogie. Gegrüber Borntrager, Berlin, 1920.

[5] Goldschmidt, V. M.: The principles of distribution of chemical elements in mineral: and rocks. Jour. Chem. Soc., 1937, pp. 655–673.

made to the mineralogy and to a general knowledge of the chemistry of the rarer elements in order to evaluate the various modes of occurrence.

APPLICATIONS OF ASSOCIATIONS.

To illustrate this method of approach, the rare earths, and columbium and tantalum are discussed below with the view of predicting their probable existence as ore minerals on the basis either of their actual occurrence in other minerals, or of the presence of closely related elements in other test minerals. Vanadium is discussed with reference to its occurrence in titaniferous magnetites, and the rare alkalies are noted as found in pegmatites.

The Rare Earths.[6] The most important rare earth mineral is monazite, a phosphate of the rare earths. Since monazite is found in the high temperature zones of the pegmatite and is one of the first minerals to precipitate, it is at once apparent that small crystals of the mineral will be found as inclusions in other later minerals if the original magmatic solution contained appreciable quantities of the rare earths and sufficient phosphates. The presence of apatite in the pegmatite would indicate that there was an abundance of phosphates at the time of formation of the monazite. Since the rare earths, especially the cerium earths, are known to be capable of replacing calcium (ionic radii: $Ca^{+2} = 1.06$ Å, $Ce^{+4} = 1.02$ Å), it is logical to select apatite as a probable test mineral since it contains both calcium and phosphates. Therefore, if the apatite molecule contains rare earths, or if the apatite mineral contains inclusions of rare earth phosphates (for instance, small crystals of monazite), it is only logical to assume that monazite may be found in the higher temperature zones of the pegmatite. However, the mere presence of rare earths in the apatite may not be a certain guide to useful deposits since it is possible that there may always be a limited concentration of rare earths in apatite. Some idea as to the values to be expected is

[6] The rare earths consist of thorium, yttrium, scandium, and elements 57 to 71 inclusive.

available from published analyses.[7] For instance, apatite from Kingston, Ontario carries 0.27–0.46 per cent rare earths, whereas apatite from Renfrew, Ontario, shows 2.27 per cent rare earths. These differences perhaps reflect the relative content of rare earths in the associated pegmatites in these localities. In cases where a concentration higher than normal is found, the development of monazite should be expected.

In the usual case where apatite occurs only as small euhedral crystals, monazite inclusions within the apatite may be detected by microscopic examination in specimens from the parent granite. The next step would be to prospect for the high temperature pegmatite bodies associated with that granite, where monazite should be expected to have crystallized.

As a practical matter, commercial deposits of monazite may be found only where running water has effected a still further concentration into placer deposits, as in India and Brazil, but these deposits must depend upon the pegmatite assemblage for their source of monazite.

Another important rare earth mineral is orthite or allanite, a hydrated silicate of calcium, ferrous and ferric iron, beryllium, aluminum, and the rare earths. If the pegmatite contains inadequate phosphate to develop apatite, the logical test mineral next to seek is a silicate, preferably some suitable variety of epidote, especially orthite or allanite. Wherever allanite is found, more rare earths may have combined with most, if not all, of the phosphate in the magmatic solutions and hence may be found also as monazite in the higher temperature phases of the same rock assemblage. In Alexander County, North Carolina, there appears to be such a rock and pegmatite assemblage, providing both allanite and monazite.

At this time, many geologists are noting the specific qualities of zircons found both in igneous and in sedimentary rocks. Zircon varies from magma to magma so definitely that the variations of zircon crystals can be used in order to distinguish between zir-

[7] Starynkevich-Borneman, I. D.: Sur le présence des terres rares dans les apatites Compt. Rend. Acad. Sci. Russie, 1924, pp. 39–41; Min. Abs. 2: 408, 1925.

cons which originate in different magmas. These examinations might be extended to the thorium and rare earth content of zircons, especially since zircon (zirconium silicate) and thorite (thorium silicate) are isomorphous. Accordingly, we should add zircon (especially the cyrtolite variety) to the list of rare earth test minerals.

Columbium and Tantalum. Many columbium and tantalum minerals are quite complex and are formed under rigorously controlled conditions at relatively high temperatures. In view of these facts, the most logical places to look for columbium and tantalum are in complex pegmatites containing relatively high-temperature minerals. Many chemically unrelated minerals, none of which are very common, are precipitated under similar conditions (for example, beryl, spodumene, topaz and zircon). Where any of these occur, search should also be made for columbium and tantalum minerals. For the same reasons, high-temperature metamorphic deposits should also be examined, especially greissen, schorl, and other "contact" mineralizations.

Columbium and tantalum show considerable resemblance to titanium. As a matter of fact, a little titanium is always present even in tantalite, $(Fe,Mn)O.Ta_2O_5$, and columbite, $(Fe,Mn)O.Cb_2O_5$.[8] In the so-called euxenite pegmatites[9] of course titanium is an important constituent with columbium and tantalum in all minerals of the euxenite group. Of the titanium minerals, titanite (essentially calcium titanate) may be serviceable as a test mineral because it is formed under the same conditions as are columbium and tantalum minerals and is easily recognized in pegmatites and contact rocks. Titanite has the further advantage of being relatively common. It is to be expected that most titanite examined would show no appreciable content of the rare elements, but in cases where titanite does contain appreciable quantities of them, of course the rarer minerals should be looked for. From a comparison of the ionic radii of columbium and titanium (ionic radii: $Cb^{+5} = 0.69$ Å, $Ti^{+4} = 0.64$ Å) and from the fact that

[8] Ellsworth, H. V.: Rare-element minerals of Canada. Canada Geol. Surv., Econ. Geol., Ser. No. 11: 26, 1932.

[9] *Ibid.*, p. 119.

columbium and tantalum tend to exist in anions (forming columbates and tantalates), as does titanium in titanite, the use of titanite as a test mineral seems reasonable. On the other hand, rutile would not serve as a test mineral because titanium here is held in the cation. Ilmenite, $TiO_2.(FeO)_x.(Fe_2O_3)_y$, might be suggested as a test mineral because of its titanium content. However, columbium and tantalum form anions (columbates and tantalates) of a definitely acid character; titanium in ilmenite is probably held in the cation, and occurs commonly in basic magmatic segregations. Analyses by v. Hevesy, Alexander, and Würstlin [10] show that the content of columbium and tantalum in rutile and titanite varies greatly in different localities, but that there is almost no columbium and tantalum prevailingly in ilmenite. Consequently, ilmenite is useless as a test mineral for columbium and tantalum, but titanite may be of some value. This case illustrates the general chemical rule that elements are associated not only as to ionic radius but also as to ionic charge (valence).

Certain minerals show a close association of zirconium and columbium. These are highly complex molecules formed in complex pegmatites and may properly be accounted for as fortuitous associations of zirconium and columbium rather than as chemical relationships. Such cases are in contrast to the association of zirconium and thorium in zircon, which is isomorphism. Zircon can hardly be expected to be a test mineral for columbium and tantalum in a chemical sense, but it may accompany physical conditions suitable for the precipitation of columbium and tantalum provided they are present. On the other hand, zircon which contains thorium in any sort of pegmatite indicates the probable presence of rare earth elements. Many of the rare earth minerals are columbate-tantalate-titanates; thorium-bearing zircon may accordingly indicate the occurrence of columbium and tantalum in the complex phases of the same pegmatite assemblage as euxenite or some other rare mineral.

[10] v. Hevesy, G., Alexander, E., and Würstlin, K.: Über das Häufigkeitsverhältnis Niob-Tantal in Titanmineralien. Zeit. für anorgan. und allgemeine Chemie, 181: 95–100, 1929.

Vanadium. Although vanadium is not found to any great extent in pegmatites, the authors wish to point out the fact that vanadium minerals are known as later introductions of basic magmatic segregations. Dunn and Dey [11] found vanadium as the mineral coulsonite, $(Fe,V)_2O_3$, dispersed in the magnetite of titaniferous magnetites in Singhbhum and Mayurbhang, India, and similar occurrences have been reported on this continent.[12] Dunn and Dey observed that the vanadium content of the titaniferous deposits was larger than that of the non-titaniferous deposits, but there was no systematic relation between the vanadium and titanium contents. Although the relation here between vanadium and titanium is not clear, it is probable that vanadium and titanium were intimately associated in the parent magma, but that in the formation of the titaniferous magnetite certain chemical relationships, the nature of which are uncertain, determined the destiny of the vanadium.

On the basis of ionic radii: $V^{+5} = 0.59$ Å, $V^{+4} = 0.61$ Å, $V^{+3} = 0.66$ Å, $Ti^{+4} = 0.64$ Å, $Fe^{+3} = 0.67$ Å), trivalent vanadium might well replace tetravalent titanium, but this does not happen. Trivalent vanadium is even closer to ferric iron than to tetravalent titanium, and apparently this at least in part explains the formation of coulsonite. However, the ionic radius relationships of titanium and vanadium may be some explanation for their association in the parent magma. Apparently, in the late magmatic stages, the titanium was deposited in solid solution with magnetite. Meanwhile, vanadium seems to have been retained in the residual magma as a minor constituent until lower temperatures were reached. Finally, it was expelled and replaced part of the earlier magnetite, forming coulsonite. This may have been effected by the replacement of ferrous oxide by either the tetroxide or the

[11] Dunn, J. A., and Dey, A. K.: Vanadium-bearing titaniferous iron ores in Singhbhum and Mayurbhang, India. Min. and Geol. Inst. of India Trans. 31: 117, 1937.

[12] The authors are under obligation to W. C. Lacy who kindly advised them regarding his own discovery of coulsonite in the highly metamorphosed rocks of the Parry Sound District of Ontario. Coulsonite occurs here in magnetite associated with ilmenite, but not in the ilmenite.

pentoxide of vanadium, producing thereby ferric oxide and a corresponding sesquioxide of vanadium according to the following equations:

$$(1)\quad 2FeO + V_2O_4 = \underbrace{Fe_2O_3 + V_2O_3}_{\text{coulsonite}}$$

$$(2)\quad 4FeO + V_2O_5 = Fe_2O_3 + \underbrace{Fe_2O_3 + V_2O_3}_{\text{coulsonite}}$$

A study of the writing by Dunn and Dey [13] convinces any reader that the relations of titanium dioxide to ferrous and ferric iron are very complex. Nevertheless, it seems clear that the ilmenite occurs with a hematite-rich magnetite assemblage. Apparently, later in the mineralizing process both hematite and ilmenite have separted from an original solid solution with magnetite. The original solutions must have been definitely oxidizing, quite aside from evidences of weathering. Certainly there are two generations of magnetite, followed by coulsonite which avoids ilmenite, even where ilmenite and magnetite are graphically intergrown. Some association of hypogene hematite and coulsonite is noted. Lacy [14] reports that hematite occurs as intergrowths with the ilmenite in magnetite associated with coulsonite at Lake Sanford, New York, and that later subordinate veinlets of hematite replace ilmenite and magnetite in the Parry Sound area. It occurs to the present writers that part of the association of hematite and coulsonite may be genetic.

Since the earlier magnetite apparently was in a partly oxidized state, presumably the magmatic vanadium was in the pentavalent state. That being so, the deposition of coulsonite by the replacement of magnetite might release ferric oxide to crystallize as specular hematite under the conditions which should be expected to prevail at the time of replacement (equation (2) above). However, lack of geological proof of this possibility leads to the suggestion that coulsonite itself with a theoretical $Fe_2O_3:V_2O_3$ ratio of 1 : 1 may well take on any additional ferric oxide which might de-

[13] Op. cit., pp. 137–160.

[14] Lacy, W. C., Private communication.

velop from the reduction of pentavalent vanadium. In such a case we should not expect syngenetic hematite with coulsonite, and this seems to be the rule.[15]

It must be emphasized that these remarks concerning vanadium apply only to high temperature deposits and are not applicable to low temperature and sedimentary deposits where the conditions of precipitation are entirely different, and wherein vanadium is generally pentavalent.

Rubidium and Cesium. Stevens and Schaller [16] have recently published a study of the rare alkalies in mica. They show that the rare alkalies rubidium and cesium are most abundant in the micas of the lithium phase of pegmatites. There is a definite association of lithium, rubidium, and cesium, but the quantitative ratio between the three alkalies varies widely from locality to locality. Nevertheless, lithium-bearing pegmatites ordinarily contain some rubidium and cesium in biotite and lepidolite. Lepidolite is a very useful guide mineral in the search for rubidium and cesium because its unusual purple or lilac color makes it easily identified in the field, as compared with lithium-bearing biotite which is indistinguishable in appearance from biotite containing no rare alkalies.

In this case lepidolite serves as an indicator of rubidium and cesium by virtue of its content of potassium which is chemically akin to rubidium and cesium. The ionic radii of the alkalies (ionic radii: $Li^+ = 0.78$ Å, $Na^+ = 0.98$ Å, $K^+ = 1.33$ Å, $Rb^+ = 1.49$ Å, $Cs^+ = 1.65$ Å) indicate that lithium is more likely to occur with sodium, and that rubidium and cesium are more similar to potassium than to either sodium or lithium. The analyses of Stevens and Schaller indicate that the sodium mica paragonite has less of the rare alkalies than have the high potassium micas. Admittedly the number of analyses is less than one might wish, but

[15] In a personal communication Mr. J. R. Balsley, Jr., advises that no hematite can be seen in the vanadium-bearing titaniferous magnetites he has examined. H. V. Ellsworth states in a personal communication that he has not noticed hematite in Canadian vanadiferous-titaniferous magnetites.

[16] Stevens, R. E., and Schaller, W. T.: The rare alkalies in mica. Am. Min. 27: 525, 1942.

as such they indicate the association of rubidium and cesium with potassium rich micas. Lepidolite may be more useful as an indicator of significant physical conditions than of chemical relationships. Lepidolite is formed during the lithium pegmatite stage [17] in which rubidium and cesium seem to be coerced into precipitation with other alkalies, especially potassium.

The authors wish to point out the fact that although rubidium and cesium are introduced into the pegmatite with lithium, the final location of rubidium and cesium in minerals depends upon their association with potassium and not with lithium, as the ionic radii of these elements indicate. This point is brought out even more clearly if we refer to Bragg's [18] discussion of the structural place of lithium in lepidolite. Following Mauguin, he explains that the electropositive atoms in the micas may be classed into three oxygen coordination groups of 4, 6, and 12. Only the smallest atoms can be enclosed by four oxygens, the medium by six, and the larger by twelve. In the case of lepidolite Bragg assigns lithium to the 6-oxygen coordination group together with aluminum. All the other alkalies have to remain with the 12-coordination elements. Only lithium seems to be sufficiently small in ionic radius to crowd itself into a 6-coordination space. Inasmuch as cesium and rubidium have ionic radii larger than those of the other alkalies, they are the least able to accompany lithium into the 6-coordination space. They must be associated with potassium, which is invariably in the 12-coordination group in micas. Consequently, in lepidolite itself there appears to be a sharp structural separation of lithium from the other alkalies and a correspondingly close association of the rare alkalies with potassium.

This collection of rare alkalies by the late-forming potassium micas of the pegmatite recalls the fact that *late* crystals of potassium feldspars in pegmatites carry considerable amounts of rubidium, cesium, and thalium [19] without regard to lithium. Never-

[17] Stevens, R. E., and Schaller, W. T.: op. cit., p. 533.

[18] Bragg, W. L.: Atomic Structure of Minerals. Cornell Univ. Press, 1937. Pp. 214–216.

[19] Goldschmidt, V. M.: op. cit., p. 661.

theless, in field examinations the feldspars offer no visible indications as to whether or not appreciable quantities of the rare elements are occluded. The feldspars, therefore, like the biotites, are not suitable test minerals for the rare alkalies. Lepidolite seems to have unique usefulness with respect to rubidium and cesium as a test mineral. Not only does lepidolite itself usually carry the rare alkalies, but it indicates their presence also in the associated syngenetic biotites and potassium feldspars.

Provided the analysis of lepidolite indicates more than a common content of cesium, then one should look definitely for the rare mineral pollucite (cesium aluminum silicate), because the addition of one extra component, cesium, justifies the expectation of a corresponding increase in the number of minerals, according to the mineralogical phase rule. Rubidium also would theoretically require another additional mineral in which rubidium is an essential constituent; such a mineral is rhodizite.[20]

DISCUSSION.

In many cases the minerals of the rarer elements which occur in pegmatites are not easily found and are often overlooked. If indications of these elements can be found in more abundant minerals which are common to many phases of a pegmatite assemblage, the search can be greatly helped. The finding of evidence of these elements in the test minerals in any phase of the pegmatite should lead to the search for rarer minerals containing these elements in specific phases of the same pegmatite assemblage; this follows from the mineralogical phase rule. All this depends upon the following premise: traces of the rare elements occur in commoner minerals in proportion to the extent to which they occurred in the parent magma. On the basis of the accepted theories of pegmatite origin and the known facts concerning the associations of the elements, particularly with regard to the role of ionic radii in the formation of crystallline substances, it is reasonable to believe that this premise is sound.

[20] Rhodizite is a borate of aluminum, potassium, cesium, and rubidium. Cesium is present in minor quantities. Rhodizite is found in pegmatites in Madagascar. See Ellsworth, op. cit., p. 12.

The method of spectrographic analysis would be of great help in examining the test minerals selected for the search. Using qualitative spectrographic analyses, Bray [21] was able to distinguish and correlate various rock bodies in Tertiary dike rocks of the Front Range, Colorado. He found that certain of the rarer elements occurred in rocks in different quantities and that the various mineral species were characterized by specific ratios between certain rare elements. By the examination of specific minerals, which he called "index minerals," collected from a variety of rocks, he was able to correlate or distinguish the rocks. Our suggestion is that certain minerals should be examined, according to the element sought. These minerals then become test minerals in prospecting for the elements desired in that particular rock assemblage.

The test mineral must neither be too common, since this greatly extends the field of association, nor must it be too rare, for in this case the problem could be solved more easily by searching directly for the rare mineral itself. It should be formed contemporaneously or immediately following the desideratum. The test mineral should contain adequate contamination of the rare elements for an approximation of its quantity, even by spectrographic analysis. Careful search will probably reveal many more occurrences of the rare elements in test minerals than are now recorded, with the result that for each rare element it will become apparent that only certain degrees of concentration will be significant for prospecting.

As aids to the solution of problems of this kind, it is suggested that the following points be borne in mind:

(1) Ionic radii and their possible effect on mineral replacement.
(2) The element may occur as an anion (columbium and tantalum, for example, form columbates and tantalates), or as a cation, or the element may be amphoteric.
(3) Relation to other elements, especially with regard to those having a tendency to form complex molecules. The micas

[21] Bray, J. M.: Distribution of minor chemical elements in Tertiary dike rocks of the Front Range, Colorado. Am. Min. 27: 425, 1942.

are notable in this respect. They are complex structures in which certain alkali metals readily substitute for one another.

(4) Isomorphism of crystalline substances.

(5) Physical chemistry of pegmatite formation. This involves (*a*) the composition of the original magmatic solutions, and (*b*) pressure-temperature-concentration relationships which determine the order of crystallization of pegmatite minerals.

SUMMARY.

Certain chemical and mineralogical associations of the elements have been proposed as a guide to the location of deposits of rare minerals in pegmatites. The rare earths, and columbium and tantalum have been discussed from the standpoint of prospecting by the examination of test minerals in pegmatites. Titaniferous magnetites should be examined for vanadium as coulsonite, as previously recommended by Dunn and Dey.[22] Stevens and Schaller show that lepidolite is a test mineral for the rare alkalies in the "lithium stage" of pegmatites.

A satisfactory test mineral must not be too abundant, or too rare in the pegmatite, and it should be capable of occluding detectable traces of the minerals or elements sought after, either by mechanical occlusion, or by means of association based on the similarity of some particular property of the desired element to the elements which compose the test mineral. From a study of the chemical and mineralogical properties of the rare element sought after, it should be possible to develop a plan for the search of a relatively abundant mineral, analysis of which would indicate the presence or absence of the rare element, and thus facilitate the field work.

We conclude that:

(1) Apatite should be a test mineral for the rare earths.

(2) High temperature epidotes are test minerals for the rare earths.

(3) Zircon is a test mineral for thorium; it may be useful with regard to the rare earths, and columbium and tantalum.

[22] Op. cit., p. 161.

(4) Titanite is thought to be a test mineral for columbium and tantalum.

(5) Lepidolite is a first-class test mineral for the rare alkalies in pegmatites.

(6) Ilmenite is a test mineral for vanadium in magnetite.

(7) The same principles may be applied in the search for other rare elements.

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CHEMICAL LIME IN CENTRAL PENNSYLVANIA.

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ABSTRACT.

High-grade limestone is present in several Middle Ordovician formations in Central Pennsylvania, but only the Valentine member of the Curtin formation has sufficient thickness for large-scale removal. The Valentine is restricted to outcrop belts northwest of a line from east of Lock Haven and Rebersburg to north of Millheim, Spring Mills, Lemont and Stormstown, in Clinton and Centre counties. The maximum thickness is 90 feet at Bellefonte, the upper 65 feet having less than two per cent of non-carbonate. Regional unconformity at the base of the overlying Nealmont limestone gradually reduces the unit toward the line of extinction, restricting the area having important thickness of stone. Moreover, the Valentine is considerably reduced in about 10 per cent of the area of outcrop in the Bellefonte district by channels filled with Nealmont limestone. Much of the stone has been removed from the most favorable areas of outcrop, but a large reserve is available to mining.

INTRODUCTION.

CHEMICAL lime can be obtained from several of the units in the middle Ordovician of Central Pennsylvania. The rocks outcrop on the limbs of the folds of the regional anticlinorium, the largest structure being the Nittany anticline (Fig. 1). The local structure of a part of the area has been mapped in the Bellefonte [1] and Tyrone [2] quandrangles. The sequence of the economically important limestones is as follows: [3]

[1] Butts, Charles, and Moore, E. S.: Geology and mineral resources of the Bellefonte Quadrangle, Pennsylvania. U. S. Geol. Surv., Bull. 855, 1936.

[2] Butts, Charles, Swartz, F. M., and Willard, Bradford: Tyrone Quadrangle, geology and mineral resources. Penna. Geol. Surv., 4th ser., Atlas No. 96, 1939.

[3] Kay, G. M.: Middle Ordovician formations in Central Pennsylvania (abstract). G. S. A. Bull., 52: 1969, 1941, with some revision.

Series Group Formation Member	Thickness at Union Furnace	Thickness at Bellefonte
Mohawkian		
Trenton		
Salona limestone		
Nealmont limestone	139 ft.	50–90 ft.
(regional unconformity)		
Black River		
Curtin limestone		
Valentine limestone *	absent	20–90 ft.
Valley View limestone	absent	50 ft.
Benner limestone		
Stover limestone	91 ft.	70 ft.
Snyder limestone *	98 ft.	75 ft.
Chazyan		
Hatter formation	102 ft.	75 ft.
Loysburg formation		
Clover limestone *	64 ft.	75 ft.
Unclassified limestone and dolomite		

* Units containing high-grade limestone.

All the limestones except the siliceous upper (Hostler) member of the Hatter formation, the upper (Rodman) member of the Nealmont limestone, and the argillaceous Salona limestone have been utilized for blast furnace flux in the past. Though the Clover limestone and Snyder limestone contain limited quantities of stone suitable for chemical lime, and have furnished stone for local lime-kilns, they are not promising as sources for large quantities of lime. The Valentine limestone is the principal producing unit. The strata have been included in the "Lowville limestone," [4] a unit that included in several areas, parts of the Nealmont, and the Snyder, Stover and Valley View limestones. The relatively pure chemical limestone has been considered to pass laterally into stratigraphically equivalent lower grade limestone.[5] The writer has concluded that the Valentine is a distinct and constant lithologic unit, restricted in distribution by a regional unconformity bevelling its top, locally reduced in thickness by channels over-

[4] Butts, Charles, and Moore, E. S.: op. cit., 1936.

[5] Field, R. M.: The Middle Ordovician of Central and South Central Pennsylvania. Amer. Jour. Sci., 4th ser., 48: 403–428, 1919.

lying the unconformity, and that strata that have been considered stratigraphically equivalent are of different ages.

The field studies have been supported by a grant from the Special Fund for Research of the Graduate Faculties, Columbia University. The writer is grateful for courtesies extended by the staffs of quarries and mines, particularly Messrs. Fred Warner

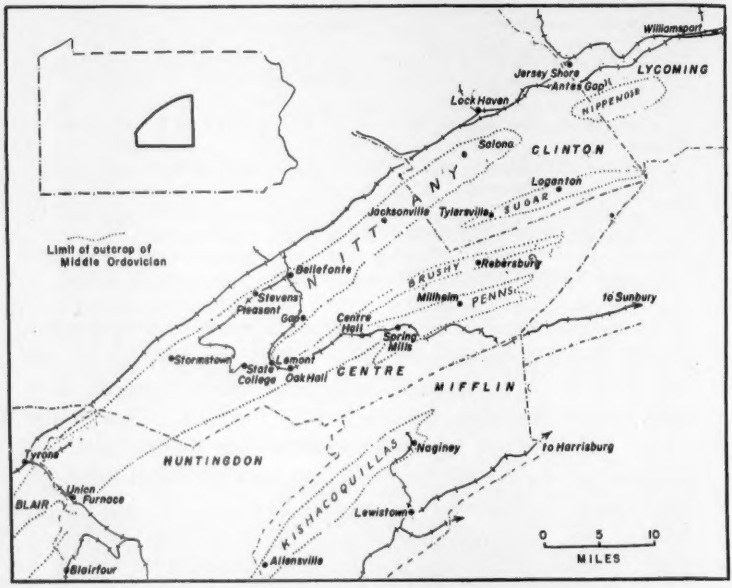

FIG. 1. Map showing localities in Central Pennsylvania.

and A. C. Hewitt of the American Lime and Stone Company, Bayard Magee of the National Gypsum Company, and R. C. Noll of Whiterock Quarries, all of Bellefonte; and by Professor W. H. Myers of Pennsylvania State College.

GENERAL STRATIGRAPHIC RELATIONS.

The chemical lime is gained from stratigraphic units that are lithologically quite constant throughout Central Pennsylvania.

The characters of the formations in single sections are representative of those in others. All but the Curtin formation are represented in the section on the two sides of the Pennsylvania Railroad cut north of Union Furnace, and in the east quarry of the American Lime and Stone Company at Pemberton, to the north; the measurements are principally from the former locality (Table I). The Curtin limestone is absent at Union Furnace through the presence of a regional unconformity that brings the lower Trenton Nealmont limestone upon successively older units southeastward, until its equivalent, the Mercersburg limestone, lies on rocks older than the Benner limestone in the vicinity of Chambersburg, Franklin County[6] (Fig. 2). The Curtin and adjoining

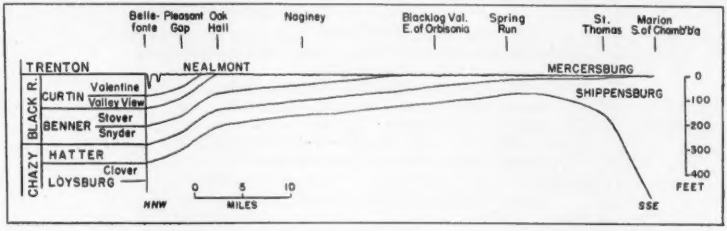

FIG. 2. Outline restored section of pre-Trenton Middle Ordovician limestones, southward from Bellefonte.

limestones are exposed near the headframe of the Bell Mine of the American Lime and Stone Company at Bellefonte (Fig. 3); the section (Table II) is similar to that published by Rosenkrans,[7] who assigned the designations to the metabentonites. The units from the "tiger-stripe" member of the Loysburg formation to the lower Valentine limestone are well exposed in the entrance cut to quarry number 23, west of Stevens. The succession is: Loysburg formation—Clover limestone, 78 feet; Hatter formation—Eyer member absent, Grazier and Hostler members, 28 and

[6] Kay, G. M.: op. cit., 1941. Craig, L. C.: Middle Ordovician of the Chambersburg region, Pennsylvania. G. S. A. Bull., 52: 1963–1964, 1941.

[7] Rosenkrans, R. R.: Correlation studies of the Central and South Central Pennsylvania bentonite occurrences. Amer. Jour. Sci., 5th ser., 27: 113–134, 1934.

TABLE I.

SECTION AT UNION FURNACE, PENNSYLVANIA.

Description of formation	Thickness Unit Ft.	In.	To base Ft.	In.
ORDOVICIAN SYSTEM				
MOHAWKIAN SERIES				
TRENTON group				
Salona limestone (Field, 1919):				
Dark, dense, plane-bedded limestone with black shale interbeds, containing several metabentonites, "0" near the base				
Nealmont limestone (Kay, 1941 *):				
Rodman member (Butts, 1918):				
Dark, brown-weathering, rather heavy-ledged, siliceous limestone, with some black chert	22	3	139	0
Unclassified members:				
Dark, dense, thin-bedded limestone with heavier interbeds; quite fossiliferous	92	1	116	9
Heavy ledge, of coquinal and of dark, coarse-textured limestone with *Columnaria* sp.	3	9	24	8
Heavy ledges of principally thin-bedded, dense limestone, with interbeds of thicker, mottled limestone and calcarenite	17	4	20	11
Dark, coarse-textured, impure limestone, having a somewhat irregular base, in two ledges	3	7	3	7
BLACK RIVER group				
(disconformity; Curtin formation absent)				
Benner limestone (Kay, 1941)				
Stover member (Kay, 1941 *):				
Ledge of dark, mottled limestone	1	2	91	1
Gray, fine-textured limestone, partly thin-bedded, with lenses of calcarenite and limestone conglomerate; contains *Distactyospongia* sp.	6	6	89	11
Heavy ledges of thin-bedded, dark limestone, with thin calcarenite beds and some black chert; *Stromatocerium* near the top	13	7	83	5
Metabentonitic clay "F," sheared, thinning and swelling; exposed on both sides of railroad cut	0	6	69	10
Heavy ledges of dark, fine-textured limestone with wavy, silty partings and thin calcarenite beds; *Cryptophragmus antiquatus* Raymond and *Distactyospongia* sp. at 37 and 55 feet from the base	69	4	69	4
Snyder member (Kay, 1941 *):				
Somewhat granular limestone with *Tetradium cellulosum* (Hall)	1	4	97	10
Medium- to coarse-textured detrital limestone, having white limestone pebbles	16	4	96	6
Fine- to medium-textured limestone, partly thin-bedded, gray and buff-weathering, with limestone conglomerate; *Girvanella*-bearing conglomerate at top repeated by small fault	21	9	80	2

TABLE I—*Continued*

Description of formation	Thickness	
	Unit Ft. In.	To base Ft. In.
Interbedded coarse-textured limestone with white-weathering limestone pebbles, and sublithographic limestone, "chemical lime"; *Tetradium fibratum* Safford abundant in upper 6 inches, *T. cellulosum*, 4 feet from base	21 8	58 5
Laminated and partly cross-bedded detrital limestone with pebbly interbeds	25 10	36 9
Gray, medium-textured, laminated, somewhat mud-cracked and rippled limestone, with white-pebble conglomerate at top	8 7	10 11
White-weathering, dense, well-bedded limestone with deep shaly reentrant at base; contact concealed	2 4	2 4
CHAZYAN SERIES		
Hatter formation (Kay, 1941 *)		
Hostler member (new *):		
Dark, impure, well-bedded, somewhat laminated limestone, sparsely fossiliferous	21 0	102 0
Dark, tan-weathering, siliceous and argillaceous limestone, massive in fracture, richly fossiliferous, less impure near base	42 0	81 0
Grazier member (new *):		
Dark, dense, heavy-ledged limestone with wavy, argillaceous partings, stylolitic, tending to weather with rows of holes; relatively non-fossiliferous	33 0	39 0
Eyer member (new *):		
Dark, impure limestone, partly calcarenite, with *Tetradium* sp.; these beds have many large heads of *T. fibratum* in a quarry north of Oakland School south of Union Furnace	6 0	6 0
Loysburg formation (Field, 1919)		
Clover member (Kay, 1941 *):		
White-weathering, dense, laminated, sublithographic limestone, "chemical lime," with prominent stylolites, to base of good exposure along bluff by railroad	41 0	64 0
Interbedded gray and buff-weathering, laminated limestone—exposed in extreme eastern end of American Lime and Stone Quarry	23 0	23 0
Unnamed member:		
Dark-weathering, dense limestone in interrupted thin, lensing beds with interbedded and penetrating buff-weathering, silty dolomite, colloquially the "tiger stripe" member		

* Type section of the unit.

TABLE II.

SECTION AT BELL MINE, BELLEFONTE, PENNSYLVANIA.

Description of formation	Thickness		Per cent insol. resid.
	Units Ft. In.	To base Ft. In.	
ORDOVICIAN SYSTEM			
MOHAWKIAN SERIES			
TRENTON group			
Salona limestone (Field, 1919):			
Dark, dense, plane-bedded limestone with black shale interbeds, containing several metabentonites, "0" near base			
Nealmont limestone (Kay, 1941):			
Dark, dense, somewhat fossiliferous, thin-bedded limestone, with thicker interbeds, becoming coarser toward top	50	50	8.77*a*
(disconformity)			
BLACK RIVER group			
Curtin limestone (new *)			
Valentine member (Field, 1919):			
Very light gray, white-weathering, dense, heavy-ledged, massive limestone—the "Bellefonte Ledge"	65 9	143 2	1.40
Very light gray, white-weathering, dense, laminated limestone; *Tetradium cellulosum* (Hall) in lower part	25 4	77 5	3.06
Yellow clay—metabentonite "A"	0 3	52 1	.....
Valley View member (new *):			
Light gray, dense, laminated limestone, with argillaceous partings	11 3	51 10	5.62
Dark, medium-textured limestone with argillaceous partings; thin clay—metabentonite "B"—at base; *T. cellulosum* abundant	1 1	40 7	.....
Gray, fine-textured, rather heavy-ledged limestone, somewhat platy near top, with some chert	10 11	39 6	11.52
Prominent parting—metabentonite "C"	0 1	28 7	.....
Gray, fine-textured, rather heavy-ledged limestone; some argillaceous partings; top mud-cracked	15 10	28 6	5.78*b* 5.40
Gray, argillaceous shale, with intercalated limestone; metabentonite "D" at base	1 4	12 8	.....
Dark, medium-textured, heavy-ledged limestone with thin, argillaceous partings; black chert near top; fucoidal	9 8	11 4	12.94
Thin beds of dark limestone with argillaceous interbeds; metabentonite "E" at base	1 8	1 8	.....
Benner limestone (Kay, 1941):			
Stover member (Kay, 1941):			
Dark-gray, fine-textured limestone, heavy-ledged, with wavy partings; *Cryptophragmus antiquatus* Raymond near base	14 7	69 6	5.04
Similar limestone, with few thin limestone conglomerate and crystalline interbeds	54 11	54 11	3.48
Stover member (Kay, 1941):			
Light gray, dense limestone, with beds of limestone-pebble conglomerate; *Tetradium cellulosum* common			

* Type section of the unit; *a*—analysis of comparable bed in base of Nealmont limestone in Chemical Lime Company mine; *b*—analysis of ten feet of beds enclosing metabentonite "C." With the exception noted, the analyses are from Miller, 1934.

46 feet; Benner formation— Snyder and Stover members, 74 and 67 feet; Curtin formation—Valley View member, 48 feet, and Valentine member, exposed for 18 feet. Most of the contacts, and the metabentonite designations, have been painted on the rock for reference.

The terms Carlim, Lemont and "Lowville" have been applied to different units at various localities. The Carlim limestone [8] included the Clover limestone and Hatter formation in the Tyrone district, the overlying Benner and much of the Nealmont being referred to the "Lowville"; in the Bellefonte district,[9] the "Carlim" included beds from the Clover to the lower Valley View, the upper part of that member and the Valentine being classed as "Lowville," and the latter included much of the Nealmont in other sections. The "Lemont member of the Carlim" in the Tyrone district is the Hostler member of the Hatter formation; it is the part of the Valley View limestone between metabentonites E and D at Bellefonte, and a part of the Nealmont at the type locality at Lemont. Confusion developed principally from the misidentification of, and misunderstanding of the ranges of species of *Maclurites, Tetradium* and *Cryptophragmus.*

At present, the principal uses of limestone are for road metal, concrete aggregate, railroad ballast, agricultural lime, and furnace-flux. Chemical composition is of prime importance in the last. In the early years of the century, great quantities were removed for blast-furnace flux, and for this purpose, quarries were opened in the Clover, Eyer and Grazier limestones, separated by a rib of highly siliceous Hostler member from larger openings in the succeeding beds to a hanging wall of Rodman limestone, the uppermost Nealmont. The largest of these were in the Tyrone region, where the higher-grade Curtin limestone is absent. There are inadequate analyses to show the composition of these units. In the American Lime and Stone Company

[8] Butts, Charles: Geologic section of Blair and Huntingdon counties, Central Pennsylvania. Amer. Jour. Sci., 4th ser., 46: 526, 1918. Butts, Charles, Swartz, F. M., and Willard, Bradford: op. cit., p. 18, 1939.

[9] Butts, Charles, and Moore, E. S.: op. cit., p. 32, 1934.

Quarry No. 2 at Union Furnace,[10] a fault repeats the Clover limestone and Hatter formation. 250 feet of beds represented by samples 1 to 6 are in the Benner and Nealmont limestones, having 86 to 93 per cent $CaCO_3$, 2 to 9 per cent $MgCO_3$, and 2.5 to 7 per cent insoluble oxides, principally silica; 45 feet in samples 7 and 8 are in the Hostler member of the Hatter formation, having 65 and 76 per cent $CaCO_3$, 10 and 8 per cent $MgCO_3$, 25 and 16 per cent oxides. More detailed analyses have been published for quarry No. 5 at Blairfour, northeast of Williamsburg;[11] the siliceous Hostler member is evidently represented in ledges 28 to 37, including 57 feet having from 5 to more than 30 per cent silica, iron and alumina; the underlying ledges, about 110 feet, extend from the lower Hatter to below the Clover limestone of the Loysburg, and the overlying 275 feet through the Benner and Nealmont to the Rodman member, represented in the upper 5 feet with 10 to 20 per cent insoluble oxide.

There are no significant thicknesses of relatively pure limestone in these sections that lie south of the area in which the Curtin limestone is preserved. Selected ledges of white-weathering, dense stone in the Clover and Snyder limestones that are quite like the important Valentine limestone at Bellefonte, have been utilized in small operations. The Clover seems to correspond to the commercially important "Mosheim" limestone that is quarried in the Shenandoah Valley from the Potomac north of Martinsburg, West Virginia, to the vicinity of Strasburg, Virginia; the rock is considerably more pure than the Clover of Central Pennsylvania. Ledges in the Snyder limestone are burned in kilns at Waterside and Ashcom, east of Orbisonia in the Blacklog Valley, and southeast of Spring Run in the Path Valley; the whole of the Snyder, reduced to 20 feet, is relatively pure at the last locality.

The Valentine limestone member of the Curtin formation, present only in parts of Centre and Clinton counties, is the im-

[10] Miller, B. L.: Limestones of Pennsylvania. Penna. Geol. Surv., 4th ser., Bull. M20: 413, 1934.

[11] Miller, B. L.: ibid., p. 233–234, 1934.

portant source of high-grade limestone. Inasmuch as the stratigraphic relations limit its distribution, they will be discussed more fully than of the other units.

THE VALENTINE MEMBER OF THE CURTIN FORMATION.

The Chemical Lime of the Bellefonte District.

The Curtin limestone (new, Curtin Gap, three miles northeast of Bellefonte, Centre County) is typically exposed in the quarry wall south of the headframe of Bell Mine, just west of Bellefonte (Table II and Fig. 3). It is separable into two members, the lower, Valley View, comprising 52 feet of impure limestone from the base of metabentonite "E" to that of metabentonite "A," and the upper, Valentine, having 90 feet of high-grade limestone extending to the unconformity at the base of the Nealmont limestone. The term "Bellefonte Ledge" is applied colloquially to the upper 65 feet of the Valentine member at this locality; it is not a stratigraphic term, for the footwall in several quarries and mines differs somewhat in horizon, and "chemical lime" at other localities in other units has been called "Bellefonte lime." The Bellefonte dolomite (Ulrich,1911) is much older, being lower Ordovician in at least its lower part; the Bellefonte sandstone is in the middle of the dolomite,[12] and though the overlying beds have been classified as Bellefonte in the Bellefonte district, they correspond to the most of the Loysburg formation that has been considered to be Chazyan farther south. The Curtin formation is exposed only in parts of Centre, Clinton and Lycoming counties. The limestone thins from 100 to 150 feet along the northwest side of the Nittany Valley to extinction along a line from Tyrone to north of Lemont, Oak Hall, and Spring Mills and south of Millheim (Fig. 5).

The Valley View member (new, from a hamlet 2 miles southwest of the type section at Bell Mine) is remarkably constant in character and thickness from the Nippenose Valley, south of Jersey Shore, to Pleasant Gap and the western end of the Belle-

[12] Butts, Charles, and Moore, E. S.: op. cit., p. 32, 1934.

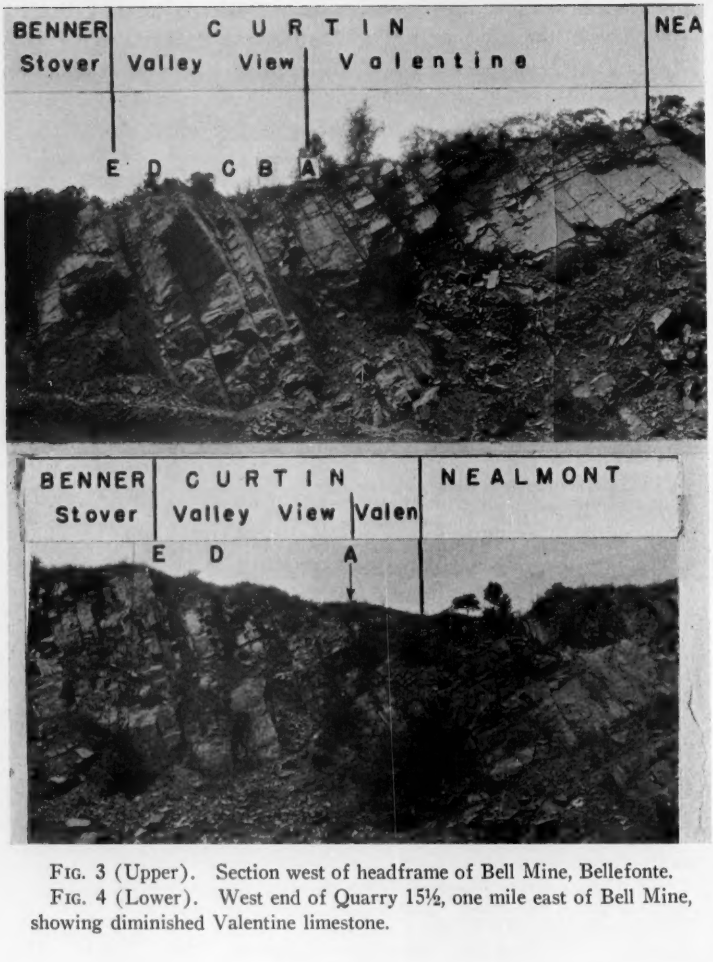

FIG. 3 (Upper). Section west of headframe of Bell Mine, Bellefonte.
FIG. 4 (Lower). West end of Quarry 15½, one mile east of Bell Mine, showing diminished Valentine limestone.

ISOPACHS - CURTIN LIMESTONE
THICKNESS REDUCED LOCALLY BY CHANNELS IN NEALMONT LS.-
CHEMICAL LIME GENERALLY RESTRICTED TO BEDS ABOVE,

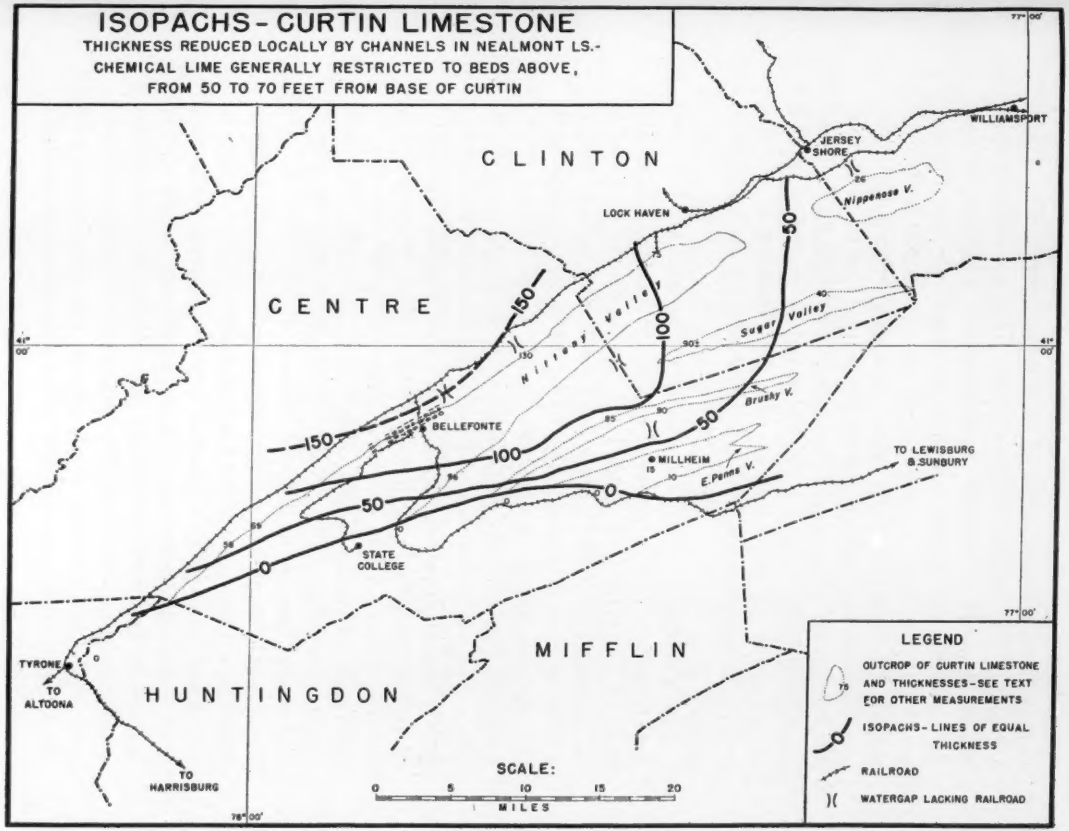

FIG. 5. Map showing distribution of thickness of the Curtin limestone; an isopachal map.

fonte district. Fifty-two feet at the type section (Table II), it thickens to 65 feet at Salona, and thins to 43 feet at Pleasant Gap. The several metabentonites form exceptional units for the demonstration of the small changes in thickness, for they are synchronous altered volcanic ash deposits. The member persists to the limit of distribution of the Curtin formation; though it is bevelled by the unconformably overlying Nealmont near the limit, the original extent may not have been much greater, for the beds are more conglomeratic and calcarenitic than normal, as exposed in the quarry in Millheim and by the bridge a mile south, where the disconformity with the Nealmont is obvious, and in the quarry south of Grays Church, northeast of Stormstown.

The Valentine member, from a "small hamlet and forge near Bellefonte,"[13] is of exceptional purity, particularly above the basal 15 to 25 feet; see Table III. The maximum thickness is rather constant in the 15 miles from the Martin Miller Quarry, 4 miles west of Bellefonte (Fig. 6) to the quarry of Whiterock Quarries east of Jacksonville, increasing from 75 feet at the former to 90 feet at Bell Mine, decreasing to 80 feet at Jacksonville. The unit diminishes to 10 feet at Salona and is absent at Antes Gap in Nippenose Valley, 20 miles beyond. Southeast of Bellefonte, there is 52 feet at Pleasant Gap, but none to the south at Lemont. The member is exposed for 40 feet west of Tylersville in Sugar Valley, absent east of Loganton, where Nealmont overlies Valley View. In Brushy Valley, 80 feet of high-grade limestone underlies Nealmont at Spring Bank, subjacent beds being unexposed; the member is missing at Millheim in East Penns Valley, and to the south and east.

In the Bellefonte district, there is general constancy, but marked local decrease. Eighty feet thick in the east end of the quarry west of the road north of Coleville (No. 21M, Fig. 6), it is only 48 feet in the west end, 1500 feet away; the Nealmont cuts gradually down, the bed overlying the Valentine in the east becoming separated by 35 feet of impure limestone partially

[13] Field, R. M.: op. cit., p. 414, 1919.

TABLE III.

CHEMICAL ANALYSES OF VALENTINE LIMESTONE.

No.	Stratigraphic unit and locality	No. samples	Thickness; feet	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3 and Fe_2O_3	Insoluble in acid
	Upper VALENTINE; "Bellefonte Ledge":							
1	Bell Mine	58	65	97.40%	1.00%	1.00%	0.40%	1.40%
2	Chemical Lime Mine No. 1	81	55	....	....	0.64	....	0.91
3	Martin Miller Quarry	31	62	....	....	....	....	1.50
4	Whiterock Quarry No. 1	6	30	....	....	0.59	....	....
	Lower VALENTINE:							
5	Bell Mine	2	25	95.50	1.50	2.00	1.05	3.05
6	Chemical Lime Mine No. 1	30	22	....	....	2.02	....	2.59
7	Martin Miller Quarry	7	15	....	....	....	....	3.05
8	Whiterock Quarry No. 1	4	15	....	....	2.43	....	....
	VALLEY VIEW:							
9	Bell Mine	1	10	92.50	1.90	5.00	0.62	5.62
10	Bell Mine	5	50	88.10	2.00	7.70	1.00	8.70
11	Martin Miller Quarry	8	15	....	....	....	....	7.52
12	Whiterock Quarry No. 1	1	10	....	....	4.20	....	....

Analyses are of suites of samples from successive beds; nos. 5, 9, 10 and 12 may be averages of several analyses; no. 10 includes no. 9.

Bell Mine, American Lime and Stone Company, Bellefonte; analyses from Miller, op. cit., p. 286, 1934; listed insoluble residue is total of silica, alumina and iron oxides.

Chemical Lime Company Mine No. 1 of the National Gypsum Company, Coleville; analyses from Bayard Magee, manager.

Martin Miller Quarry; analyses from Bayard Magee, National Gypsum Company.

Whiterock Quarry No. 1, Pleasant Gap; analyses by C. J. Lewis, through R. C. Noll, president, Whiterock Quarries; nos. 4 and 8 successive in quarry face, not extending to top of Valentine limestone, no. 12 of uppermost Valley View.

coarse, calcite-sandstone or calcarenite. The "Bellefonte Ledge" so thins in the mine below that it has not been removed for 2000 feet along the strike. More extreme thinning is shown in the quarry west of the Pennsylvania Central Railroad (No. 15½), the Valentine being but 17 feet thick, overlain by 32 feet of coarse calcite sandstone of the basal Nealmont, with disconformity of as much as 4 feet in the western corner of the opening (Fig. 4). The quarries to the west (No. 17) and east (Nos. 15 and 13) have about 80 feet of Valentine.

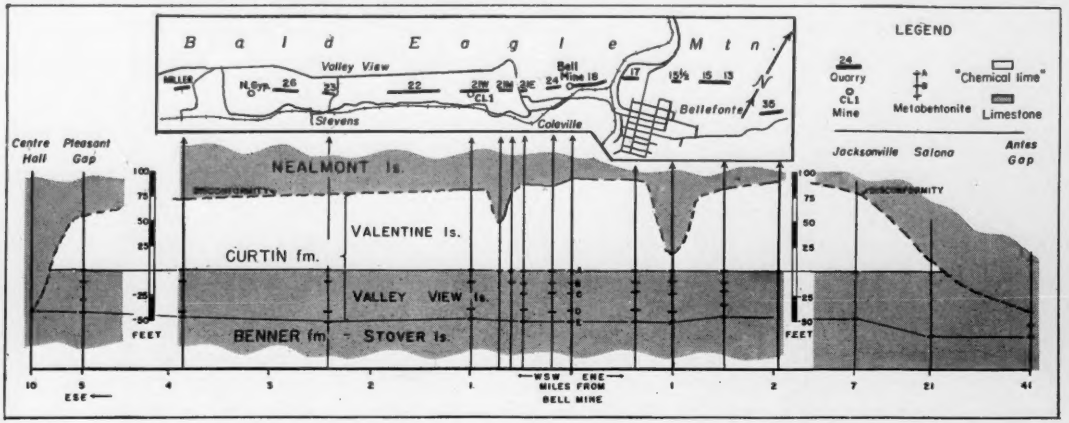

FIG. 6. Sections of Curtin limestone, showing succeeding regional unconformity and local disconformity.

Thus, the Nealmont limestone bevels the Valentine regionally, and fills channels within it locally. There seems no way of anticipating the presence of channels other than through examining surface exposures, and drilling. If the quarry exposures and mines are representative, the "Bellefonte Ledge" is so thinned as to be unminable in about 10 per cent of the outcrop. The mine of the American Lime and Stone Company north of Coleville suggests that the channel there has a northwestward trend, and thus down the dip. In areas where the Valentine is concealed, its outcrop can be located on the surface by identification of exposures of other members in the sequence, and consideration of structure. Faults are responsible for offset and cutting-out of the member in several places; the fault north of Bellefonte offsets the outcrop about one-fourth mile, and minor thrust faults have been encountered in the mines west of the town.

There are local impure beds within the Valentine that represent areas of concentration of impurities in the original deposition. In analyses of the "Bellefonte Ledge" at Bell Mine,[14] the per cent of silica, alumina and iron oxide reaches a maximum of 1.60, and that of $CaCO_3$, a minimum of 97.32 in single samples from one foot intervals. In the Chemical Lime Company Mine analyses (Table III), insoluble residue totals 4.41 per cent in one sample from two-thirds foot; four samples from 3 feet exceed 2 per cent in the thickness of 55 feet of high-grade limestone.

In summary, the Valentine limestone is the source of the "chemical lime" that is mined and quarried in the Bellefonte region. The distribution of the member is controlled by an unconformity that succeeds, gradually bevelling it to extinction southeastward, and locally having channels that reduce the thickness of best stone, or cut it out.

COLUMBIA UNIVERSITY,
NEW YORK CITY,
December 17, 1942.

[14] Miller, B. L.: op. cit., p. 287.

GOLD ORES OF THE LITTLE LONG LAC AREA, ONTARIO.

H. S. ARMSTRONG.

ABSTRACT.

In the Little Long Lac Area gold occurs in two main types of orebodies. The first, exemplified by the Number 2 and Number 30 vein systems at Hard Rock, and the North and West ore zones at MacLeod-Cockshutt, consists of massive sulphide replacement bodies in iron formation. The second consists of silicified zones associated with intrusive acid porphyries, found in the South ore zone at MacLeod-Cockshutt, and in the orebodies at Magnet Consolidated, Bankfield, Tombill, and Jellicoe. Gold-quartz veins associated with acid porphyries, a variety of the second type, are found in the Number 1 vein system at Hard Rock, and the 210 quartz vein at MacLeod-Cockshutt. The orebodies at the Little Long Lac mine are confined to shear zones in arkose, and do not conform to the above general classification.

Hand specimens and polished sections typical of these orebodies have been studied. Composite diagrams representing the mineral paragenesis in each orebody or mine have been drawn up and are discussed in this paper. These eleven diagrams are combined in a table representing a generalization of the mineral relations over the entire area. In addition, the sequence of mineralization is presented in terms of radicles.

From the evidence of mineral sequences, and certain other investigations, it is apparent that the ore deposits of the Little Long Lac area may be correctly placed in Lindgren's upper hypothermal, or lower mesothermal, zone. Possible sources of the ore-depositing solutions are discussed, but no final statement made.

INTRODUCTION.

Location.

THE Little Long Lac area is about 75 miles north of Lake Superior in the Port Arthur mining division of the District of Thunder Bay, Ontario. The area comprises six townships: Houck, McQuesten and Fulford to the north, and Ashmore, Errington and Lindsley to the south of the Port Arthur-Longlac branch of the Canadian National Railway. The seven mines dis-

cussed are distributed through Errington, the western part of Ashmore, and the eastern part of Lindsley townships.

The town of Geraldton, on the railroad, 21 miles west of Longlac, is a convenient base for operations. Transportation by aeroplane is available. During the summer of 1940, the highway connecting Port Arthur and Geraldton was opened to traffic.

The history of the development of the area has been recorded by E. L. Bruce.[1] The first mine in operation in the region was the Little Long Lac mine, which began production in November, 1934.

General Geography.

Geraldton is at an altitude of 1,110 feet above sea level. The relief is typical of the Canadian Shield: prominent hills or rock ridges are rare and swamps and small lakes are numerous. There are a few larger lakes, but they are relatively shallow. The drainage of this area is sluggish, owing to the proximity of the height of land. Little Long Lac (Kenogamisis lake) drains northeast to James Bay by way of the Kenogami river.

Well-developed esker ridges and other glacial deposits are conspicuous not only from the air, but in aerial photographs as well. The general trend of the ridges is northeast-southwest, but this is by no means constant. As a result of the deposition of a thick mantle of glacial debris, rock outcrops are neither abundant nor extensive.

The marshy areas are characteristically spruce, tamarac, and cedar muskegs, with some cedar and alder swamps. Drier sections have a forest cover of spruce and jackpine, or of poplar and birch. In recent years, forest fires have cut swaths through the region and destroyed much timber which would have been of value in the early stages of mine and prospect development.

Steam was originally the source of power for the early development of the mines in the area. Electrical power is now available from the Nipigon river, 100 miles distant.

[1] Bruce, E. L.: Little Long Lac Gold Area. Ont. Dept. Mines, 44, pt. 3: 3–5, 1935.

GENERAL GEOLOGY.

Stratigraphy.

The stratigraphy of the Little Long Lac area has been outlined by Bruce.[2] The following discussion is taken from his report, supplemented by personal observations made during the summer of 1940. The table given here is a modification of that of Doctor Bruce.

QUATERNARY	
Recent:	Clay, peat.
Pleistocene:	Till, sand, gravel.
	Unconformity
PRECAMBRIAN	
	Quartz diabase dikes.
	Intrusive contact
Later Precambrian:	Granite porphyry, feldspar and quartz porhpyry dikes.
	Intrusive contact
	Diorite, diorite porphyry.
	Intrusive contact
"Timiskaming-type":	Greywacke, arkose, impure quartzite, chlorite schists.
	Iron formation.
	Conglomerate.
	Unconformity
"Keewatin-type":	Greenstone, volcanic fragmentals, chlorite schists, and thin beds of black slate.

"Keewatin-type." Basic volcanics, generally andesitic in composition, constitute most of this series. Subordinate to the lavas

[2] Ibid., pp. 10–27.

are a few lenses of agglomeratic and tuffaceous rock, and some narrow bands of black slate. Weathering of the andesites shows that they are ellipsoidal or pillow lavas. Other varieties of this rock, in some places coarse-grained, include amygdaloidal and massive greenstones, the latter often associated with ellipsoidal lavas. The coarse grain of the massive greenstones may well cause them to be mistaken for diorite, with which they are identical in chemical and mineralogical composition. Chlorite schists commonly result from the operation of shearing stresses on the basic volcanics.

Observations taken in order to determine the attitude of the volcanics are inconclusive, the outcrops being too widely spaced. The strike of the schistosity is nearly east-west, the dip almost vertical.

"Timiskaming-type." Most of the rocks of this series are extremely varied clastic sediments. Although no definitely basal conglomerate has yet been uncovered, a somewhat continuous conglomeratic member has been found close to the Keewatin greenstone. Most of the conglomeratic beds are lenticular and discontinuous. Pebbles of granite, feldspar porphyry, quartz, chert, and a fine-grained greenstone-like rock have been found in matrices varying from slaty and schistose chloritic to massive fine-grained and quartzose material. No fabric analyses have yet been made on the pebbles although their spherical to ellipsodial shapes would lend themselves to such investigations. A careful search was made for conglomerate boulders in these conglomerates, but none was found.

Commonest of the rocks of the Timiskaming type are gray, in some places greenish, greywackes of which quartz is the most prominent constituent. As the proportion of feldspar, usually oligoclase, increases, the rocks may better be termed arkosic greywackes or arkoses. Among the commoner accessory minerals, variable in quantity, are amphibole, calcite, chlorite, and magnetite. The east-west shearing in the area has in many places obscured the bedding of these fine-grained sediments. Gradations in grain size, however, are well developed in some places, where

observations have indicated that the tops of the beds are toward the south.

Quantitatively less important than the greywackes, but of considerable interest to students of ore deposits, are the beds of iron formation on which Brant [3] made geophysical surveys during the summer of 1939. The extensive outcrops at one locality illustrate the well-banded character: layers of magnetite, hematite, and quartz alternate with bands of red or white fine-grained silica. The richest iron formation bands contain less than 40 per cent of iron, and therefore, at the present time, are not considered to be iron ore. The origin of the iron formation remains an open question.

Fine-grained chlorite schists are interbedded with clastic sediments in some places. Bruce [4] has examined thin sections of some of these and has interpreted one type as a dike or sill of diorite. He discounts the theory that some of the beds are tuffaceous, and explains the high chlorite content on the basis of a considerable proportion of ferrous iron in the original rock. The recrystallization of such a rock would result in the formation of chlorite.

Later Precambrian. The earlier Precambrian greenstones and sediments have been cut by intrusive rocks of at least three ages.

(i) Diorite and Diorite Porphyry. These dark-colored or speckled rocks form irregular or oval-shaped masses and elongated sill-like lenses. Two large areas, possibly irregular stocks, as well as numerous smaller areas and sills occur in the region. The rock of the stock-like masses has a granitic texture. The variable color of the rock types is a result of considerable variation in the proportion of light to dark minerals. Andesine is the most abundant mineral, even in the darker varieties; the remainder of the rock is made up of dark-green to black amphiboles, quartz, calcite, and chlorite.

Massive diorite is difficult to distinguish from the coarse-

[3] Brant, A.: A geophysical and geological survey of the Little Long Lac Area. Ont. Dept. Mines, Prelim. Rep., May, 1940.

[4] Bruce, E. L.: Op. cit., pp. 15–16.

grained lavas. The discrimination between volcanic or sedimentary chlorite schists and intensely sheared fine-grained diorites which have become chlorite schists is also uncertain.

(ii) Acidic Intrusives. Two types of soda-rich intrusives occur in the area. A soda-granite porphyry mass of unknown shape contains abundant albite and considerable quartz; the remainder comprises orthoclase, apatite, and the secondary minerals calcite, chlorite, epidote, and sericite.

Many small masses and dikes of feldspar and quartz porphyry constitute the second type. Albite is the common phenocryst mineral, but the dike rocks are marked by abundant orthoclase and less quartz than the soda-granite porphyry. Quartz, calcite, sericite, and chlorite are the chief constituents of the ground mass.

The general trend of the dikes, which are themselves sheared, is parallel to the general strike of the country. The dikes cut all the rocks previously mentioned, and although presumably not all precisely contemporaneous, analyses [5] suggest that they probably came from a common magmatic source.

(iii) Quartz Diabase. Quartz diabase dikes, usually less than 120 feet wide, are common throughout the area wherever they are not covered by overburden. The general trend of these vertical dikes is north-south. Labradorite and augite crystallize in characteristic ophitic texture; quartz, magnetite and hornblende are primary accessory minerals, chlorite and epidote are secondary.

These dikes are classed as Keweenawan in age by analogy with similar rocks throughout Northern Ontario, particularly those near Lake Nipigon, about 50 miles to the west.

Pleistocene. Unconsolidated gravels, sands, and clays lie unconformably upon the Precambrian rocks. Bruce [6] notes the presence of probably pre-Pleistocene weathered zones in some of the prospects. In some places as much as 60 feet of sand and gravel have been found forming irregular knolls and ridges or elongated eskerine deposits. No varved clays have been found in the region.

[5] Ibid., pp. 21–22.

[6] Ibid., p. 25.

Recent. Peat and moss deposits are accumulating in the lakes, marshes, and swamps of the present time. Some of the peat deposits have attained notable thicknesses.

Structure.

The structural relations of the volcanic and sedimentary series have been largely obscured by the heavy drift overburden. The direction of strike and amount of dip may be determined from the conglomerate lenses and bands of iron formation, but in the greywackes extreme care must be exercised to distinguish between bedding and shearing. Flat dips to the north or south have been noted, but in general the beds are nearly vertical.

The somewhat continuous band of conglomerate, which has been mentioned previously as outcropping close to the Keewatin greenstone, contains some pebbles which have been derived from the lavas. The sediments are, therefore, younger than the greenstone, and because they lie to the south, the structure may be interpreted as synclinal. This inference is supported by the relations between bedding, schistosity, and the plunge of folds in the iron formation.

Despite the scattered nature of the outcrops, the sediments have proved to be the most amenable to structural investigations. Bruce [7] has shown that the southern limb of the syncline probably lies well to the south of Little Long Lac, possibly displaced by the granites which are found in that direction. He has traced a gradation southward from the basal conglomerate through a zone of heterogeneous sediments into a wide zone of slaty greywackes.

The gold mines discussed in this paper thus lie within a major syncline which has a westward plunge of about 30°. Steeply dipping, closely folded minor structures complicate the general synclinal structure.

The recognition of faulting is made difficult by the scarcity of outcrops and by the discontinuous character of key members. Strike faulting has probably occurred as evidenced by the strongly developed east-west shear planes. Low angle faults have been

[7] Ibid., p. 17.

met with in underground developments. In other regions the displacements of diabase dikes serve as a useful indicator of faulting, but here there seems to be little displacement, at least at the surface.

THE ORE DEPOSITS.

The geology and orebodies are described from data available in published reports as well as from information supplied personally by officials of the various mines. The descriptions of the ores are based on the results of examination by the writer of hand specimens and polished sections. The diagrammatic representations of the mineral paragenesis at each mine are composite diagrams compiled from similar tables for individual polished sections and hand specimens. As a general rule, no single specimen will present the complete sequence of any one composite table.

In the following descriptions, the term *bleb* is used in a sense which differs to some extent from the dictionary definition. The definition implies small bubble-shaped or drop-shaped masses. The writer uses the term to signify any very small anhedral mass within another, regardless of whether it be angular or rounded. The term, however, does not include minute regular crystal inclusions such as are found in some sections.

Hard Rock Gold Mines, Limited.

General Geology. The ore deposits at the Hard Rock mine are associated with sediments, porphyry masses, and diabase dikes.

The sediments are greywackes, generally fine-grained and rather dark grey in color. Bedding may be distinct, but in places it is obscured by shearing to such an extent that the rock is more properly termed slate or slaty greywacke. Commonly interbedded with the greywacke are bands of hematite, magnetite, and jasper varying in width from one to six inches and separated by as much as five feet of greywacke. All gradations from this very "light iron formation" to finely laminated "heavy iron formation" are to be observed. The latter consists of bands of greywacke or quartz alternating with magnetite and hematite or jasper. Diamond drill intersections indicate lenses of conglomerate in the

greywacke, in some places exceeding 100 feet in thickness. Close folding and fracturing of these members have resulted in a highly contorted sedimentary series.

Two types of porphyry, both later than the sediments, outcrop on the property and also have been encountered in the underground workings. The basic type outcrops as diorite porphyry and chlorite schist. The difficulty of distinguishing between the latter and volcanic material has been discussed. The larger area of diorite porphyry is probably an irregular boss.

Near the western side of the Hard Rock group of claims, and extending several hundred feet on to the eastern part of the adjacent MacLeod-Cockshutt group, is an irregularly elliptical mass of albitite porphyry. At one time covered with drift and swamp, the mass has been uncovered and now rises as a low hill of light-weathering, pale gray, massive rock cut by veinlets of quartz. The porphyry body is a pipe-like intrusion plunging to the westward at an angle of 30°. Underground development has shown tongues of porphyry extending from both ends of the pipe along bedding and shear planes in the greywacke. The margins have a banded structure as a result of the *lit par lit* mode of emplacement of the porphyry.

Diabase dikes are not numerous. The albitite porphyry pipe is cut by two narrow sub-parallel dikes trending east of north. Similar narrow dikes which do not outcrop have been encountered underground. None of these dikes bears any genetic relation to the ore deposits.

The Orebodies. The orebodies at the Hard Rock mine very closely resemble those at the adjacent MacLeod-Cockshutt with which they are continuous. Three different ore types have been developed, namely, the Number 1, Number 2 and Number 30 vein systems.

The Number 1 system comprises free gold-bearing quartz veins within the albitite porphyry. These veins closely resemble the 210 Quartz Vein at MacLeod-Cockshutt insofar as structural relations are concerned. Certain differences in mineralogy are evident in the high pyrite content of most of the Hard Rock veins.

Only where the quartz is extremely fine is gold found in visible quantities. The veins of this system are not being worked at the present time and no specimens were available.

The Number 2 system differs somewhat from the South Ore Zone at MacLeod-Cockshutt. At both mines the ore is associated with the main albitite porphyry pipe. The difference lies in the fact that at MacLeod-Cockshutt the second associated rock is greywacke, while at Hard Rock it is iron formation. The Number 2 vein system comprises beautifully banded ore, alternate layers of closely folded iron formation having been replaced by sulphides. This banded ore is cut transversely by quartz-tourmaline veinlets which represent fracture fillings with some replacement. No production is being maintained from this system at the present time.

The Number 30 system, or North orebody, is the eastward extension of MacLeod-Cockshutt's North Ore Zone. Like that ore, the Hard Rock ore from this system is a massive sulphide replacement of greywacke bands in iron formation. The structure of the Hard Rock system, however, is not so highly irregular as that of the MacLeod-Cockshutt ore zone. A single vertically-standing large drag-fold apparently relieved the folding stresses which gave rise to the highly complex and irregular structures to the west. The massive sulphide ore is fairly constant across the section of the fold, as also along its western arm. Developed over a stoping length of 850 feet, this orebody produced 97,568 tons of ore, averaging $8.56 per ton, during the nine months ending September 30, 1941.

Mineral paragenesis (Figs. 1, 2, 3, 7, 11). The mineralogy of the Hard Rock ores is rather simple. Twelve metallic minerals were identified, of which pyrite and arsenopyrite are the most abundant. Free gold was observed in more than half the polished sections examined, but it is not visible in the hand specimens, and none was "high grade."

The following composite tables of paragenesis are compiled for the two main orebodies, the Number 2, and the Number 30 vein systems:

TABLE 1.

NUMBER 2 VEIN SYSTEM.

TABLE 2.

NUMBER 30 VEIN SYSTEM.

Discussion of the Tables. Table 1. The absence of arsenopyrite is a noteworthy feature of these ores. Although arsenopyrite was not observed in hand specimens or polished sections, it seems very likely that additional sections would reveal its presence, since in this general area arsenopyrite, like pyrite, is almost ubiquitous. Pyrite was the first mineral to crystallize; in the sections available it forms large masses which were cracked during the period of fracturing that followed. The cracks in the pyrite were filled with quartz which carries pyrite conforming

to the quartz. Some pyrite in the sections is conformable to quartz, indicating that where no fracturing has taken place, there is an overlap in the relationship between quartz and pyrite.

The gray mineral identified as ilmenite conforms to and in some places replaces pyrite and quartz. Its relation to the minor sulphides is not clear; smooth and irregular boundaries were observed but no crystal faces of the minor sulphides were found. Ilmenite likely occupies the position indicated in the diagram.

Pyrrhotite, sphalerite and chalcopyrite occur as minute rounded and irregular blebs, occasionally following fractures, in the earlier pyrite grains (Fig. 11). Pyrrhotite and sphalerite have mutual boundaries which have served, in some places, as channels for the infiltration of chalcopyrite which replaces them. In other places chalcopyrite seems to be contemporaneous with sphalerite and pyrrhotite. Cubanite was seen in a single bleb associated with chalcopyrite. Calcite conforms to all the minerals appearing above it in the diagram.

A second period of fracturing is indicated by the presence in one polished section of a vein of quartz and calcite which carries minute euhedra of pyrite. This may be regarded as a third age of pyrite. Black acicular crystals in the quartz veins of the hand specimens are needles of tourmaline which crystallized in part before the quartz but probably later than the pyrite. The fact that some of them conform to crystal outlines of quartz is suggestive of an overlap in the sequence of deposition. A second generation of calcite which occurs in the veinlets is prevailingly later than the second quartz, but in some places mutual boundaries of the two minerals indicate overlap.

The exact position of gold in the sequence is uncertain. It probably was introduced by the quartz-tourmaline vein solutions, but the possibility that it came in with the earlier quartz and minor sulphides should not be overlooked. Gold occurs as irregular blebs in the early pyrite where it fills spaces between the closely set pyrite crystals. It is also found along the contacts of pyrite with the minor sulphides, these contacts apparently having afforded easy access of the gold-bearing solutions.

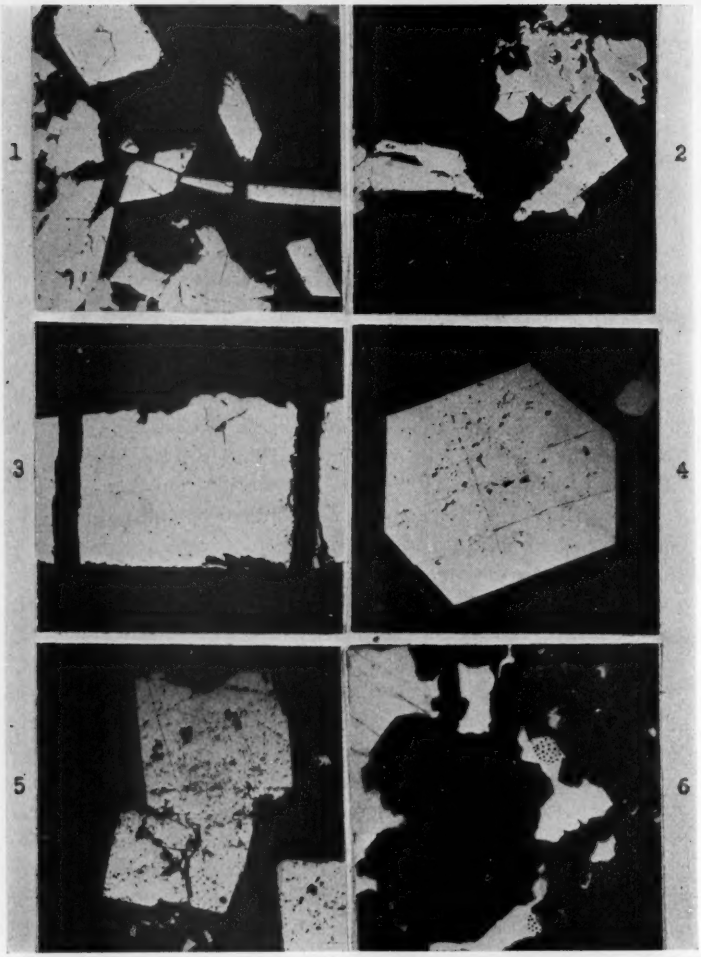

FIG. 1. Diamond- and lath-shaped euhedra of arsenopyrite. Hard Rock Gold Mines, Limited. Arsenopyrite (white), quartz and calcite (black and gray). × 50.

FIG. 2. Skeletal crystals of arsenopyrite. Hard Rock Gold Mines,

During a late period of movement, the quartz-tourmaline veins have been locally faulted and slickensides developed.

Table 2. Arsenopyrite occurs as large well-developed crystals with euhedral outlines (Fig. 1) and as skeletal crystals (Fig. 2). Many of these crystals have been broken across (Fig. 3), the fractures being filled with quartz and metallics. Unfractured pyrite conforms to arsenopyrite but is, in part, automorphic against quartz. A considerable overlap between pyrite and quartz is indicated by the fact that much of the pyrite conforms to quartz crystal outlines. In several of the sections a period of shearing is suggested by the parallel alignment of flakes of graphite and the rounding of pyrite masses, and quartz may have been introduced or recrystallized during this shearing. The overlap relationship of pyrrhotite and quartz was seen in some sections where quartz conforms to pyrrhotite outlines. The deposition of pyrrhotite continued past that of sphalerite, resulting in the overlap relationship shown in Table 2. Galena and sphalerite have mutual boundaries in some sections, but for the most part galena conforms to sphalerite and has mutual boundaries with some of the pyrrhotite. Chalcopyrite in places conforms to galena and pyrrhotite, but was elsewhere observed to have mutual boundaries with these

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Limited. Arsenopyrite (white and somewhat mottled—the mottled appearance is due to reflection pleochroism), quartz (black), calcite (dark gray). × 50.

FIG. 3. Arsenopyrite lath fractured transversely. Hard Rock Gold Mines, Limited. Arsenopyrite (white—note the matching walls in the fractures), pyrite (light gray), quartz and calcite (dark gray). × 50.

FIG. 4. Automorphic replacement of argillite by pyrite. Bankfield Consolidated Mines Limited. Pyrite (light gray—note the manner in which the "grain" of the rock is transected), non-metallics (black). × 50.

FIG. 5. Euhedron of pyrite fractured and displaced. Tombill Gold Mines Limited. Pyrite (light gray—note the manner in which the larger part has broken the smaller), quartz (black), calcite (dark gray). × 50.

FIG. 6. Galena with euhedral gold. Magnet Consolidated Mines Limited. Galena (white), gold (grayish, scratched—note the euhedral grains, stippled, surrounded by galena in the middle of the figure), quartz (dark gray). × 110.

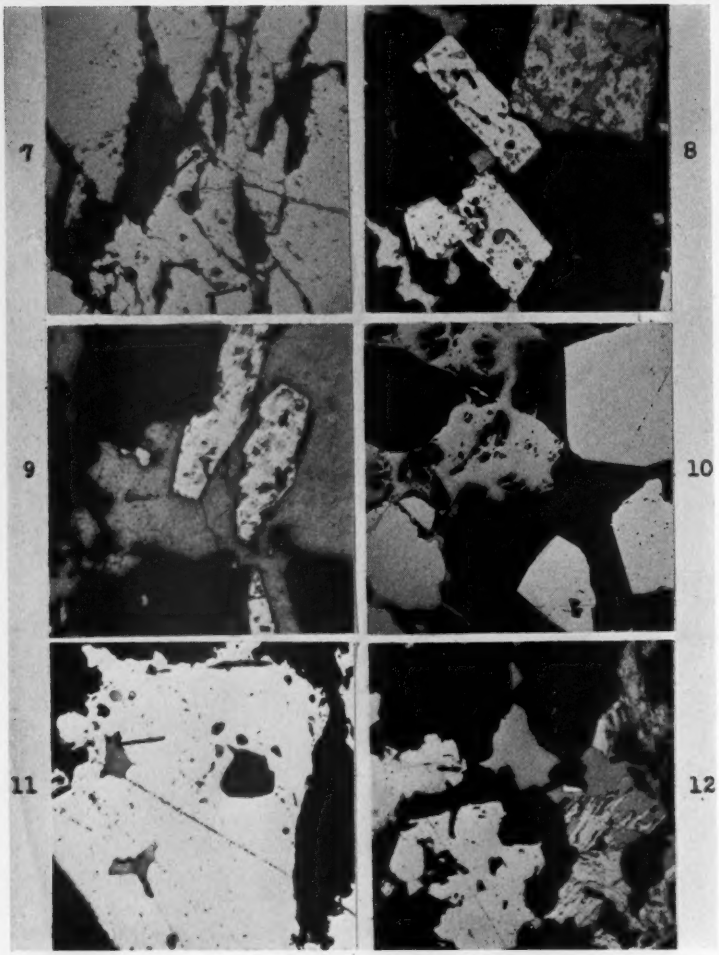


FIG. 7. Gold with quartz in fractured arsenopyrite. Hard Rock Gold Mines, Limited. Arsenopyrite (white), quartz (dark gray), magnetite (light gray), gold (indicated by arrows). × 110.

FIG. 8. Gold associated with pyrite and quartz. Bankfield Consolidated

two minerals. The gray mineral identified as ilmenite(?) is later than chalcopyrite, in some places replacing it, in others conforming to the outlines of the minerals which precede it in the table. Minute crystals of a mineral identified as leucopyrite are associated with pyrite and conform to its outlines. Although not observed in association with ilmenite, the position noted for it in the table is probably correct.

During the second period of fracturing, which followed the deposition of leucopyrite, all the former minerals were broken transversely. Minute euhedra of arsenopyrite are embedded in the quartz-calcite filling of the interstices. Calcite conforms to the later arsenopyrite but preserves its outlines against quartz with only a slight overlap in the sequence. A second age of pyrite occurs as small grains which are in overlap relationship with quartz. Most of the pyrite conforms to quartz, but some is automorphic against it. Pyrrhotite was found alternating with pyrite in a veinlet in one of the hand specimens. The position of gold is difficult to ascertain definitely (Fig. 7). It was probably brought in along with these later solutions and deposited last. The late calcite shown in the table represents calcite, possibly of supergene origin, which has crystallized in vugs.

Mines Limited. Gold (light gray), pyrite (white), quartz (black). × 110.

FIG. 9. Gold associated with arsenopyrite and quartz. Tombill Gold Mines Limited. Gold (light gray), arsenopyrite (white), quartz (black). × 110.

FIG. 10. Pyrite with quartz and chalcopyrite. Tombill Gold Mines Limited. Pyrite (white), quartz (black), chalcopyrite (light gray). × 50.

FIG. 11. Inclusions of chalcopyrite and pyrrhotite in pyrite. Hard Rock Gold Mines, Limited. Pyrite (white), pyrrhotite (dark gray), chalcopyrite (light gray—lath of cubanite indicated by arrow), quartz (black). × 110.

FIG. 12. Intergrowth of pyrrhotite and leucopyrite. Magnet Consolidated Mines Limited. Pyrrhotite (medium gray), leucopyrite (light gray, dendritic mineral), pyrite (white), quartz (black). × 110.

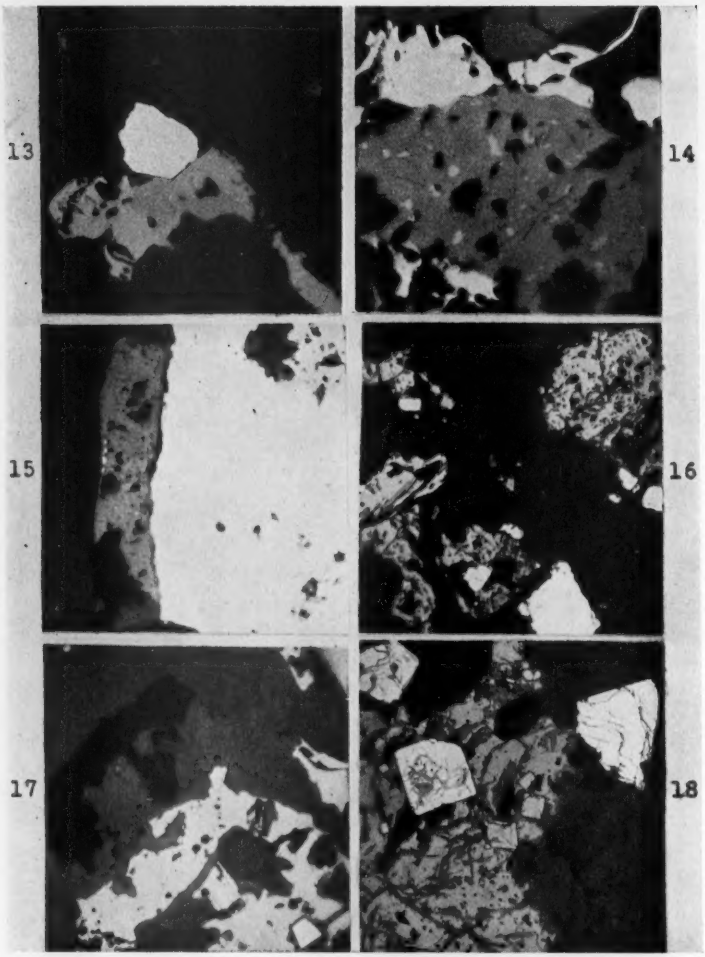


FIG. 13. Pyrite, pyrrhotite, and chalcopyrite. Magnet Consolidated Mines Limited. Pyrite (white), pyrrhotite (medium gray), chalcopyrite (light gray), quartz (black). × 110.

FIG. 14. Chalcopyrite and sphalerite. Tombill Gold Mines Limited.

MacLeod-Cockshutt Gold Mines Limited.

General Geology. The rocks in the MacLeod-Cockshutt group of claims are identical with those in the adjacent Hard Rock group, but the types of rock which outcrop afford a few points of difference. At the western boundary of the group a bed of conglomerate outcrops. At one place it is thirty feet thick and contains pebbles of granite, porphyry, and quartz embedded in a foliated quartzose matrix. Diabase dikes in the MacLeod-Cockshutt property do not outcrop, but occur only as fine-grained black dikes in the underground workings. A third difference is the presence of more iron formation in the MacLeod-Cockshutt than in the Hard Rock claims.

The Orebodies. The geology and structural relations of the ore deposits at MacLeod-Cockshutt have been investigated by H. F. Morrow.[8] He discussed three distinct types of orebodies at

[8] Morrow, H. F.: Geology and Ore Deposits of the MacLeod-Cockshutt Gold Mines, Little Long Lac Area, Ontario. (Unpublished M.A. thesis, Dept. of Geol., Queen's University, 1940.) Pp. 13–39.

Chalcopyrite (white—smooth contacts and presence as exsolution blebs suggest contemporaneity of chalcopyrite and sphalerite), sphalerite (gray), quartz (black). × 120.

FIG. 15. Hematite between quartz and pyrite in veinlet. MacLeod-Cockshutt Gold Mines Limited. Hematite (light gray band), pyrite (white), quartz (dark gray), magnetite (light gray grains scattered in pyrite). × 55.

FIG. 16. Ilmenite with pyrite and quartz. Bankfield Consolidated Mines Limited. Ilmenite (gray), pyrite (white—contains tiny inclusions of gold), quartz (black). × 110.

FIG. 17. Malachite, limonite, and chalcocite with chalcopyrite, pyrite, and quartz. Bankfield Consolidated Mines Limited. Pyrite (white euhedral grain), quartz (black), chalcopyrite (light gray), chalcocite (lighter gray bands in and around chalcopyrite), limonite (dark gray bands associated with chalcocite), malachite (radiating clusters of needles). × 110.

FIG. 18. Chalcopyrite and pyrite with chalcocite-limonite veinlets. Bankfield Consolidated Mines Limited. Chalcopyrite (light gray), pyrite (white), chalcocite (lighter gray bands in chalcopyrite) limonite (dark gray bands associated with chalcocite), quartz and calcite (dark gray). × 55.

the mine: the South Ore Zone, the North Ore Zone, and the 210 Quartz Vein. Recent developments since the summer of 1940 have indicated the presence of a fourth orebody, to be known as the West Ore Zone.

The South Ore Zone is one of fracturing and shearing, closely following the contact between the albitite porphyry and greywacke. Gold values are limited to the sheared rocks which include the porphyry where the tongues of that rock are narrow. Massive sulphides comprise the major ore minerals; in some places tongues of sulphides have replaced the greywacke along shear and bedding planes.

The North Ore Zone is composed of lenses of sulphides in a band of iron formation. The lenses are short and wide and lie close together along the contorted contacts between the more typical iron formation and greywacke containing a low percentage of iron. In places the structure of the ore shoots is very irregular with finger-like tapering ends. The sulphides have selectively replaced sheared greywacke along the shear planes, rather than the massive iron-rich bands. Many sulphide veinlets transect the shear planes of the greywacke where cross fractures afforded easy access of ore-bearing solutions. The stoping length of the ore zone is about 600 feet, the width averages 12 feet, but varies within much wider limits.

The 210 Quartz Vein is a closely folded saddle that lies entirely within the albite porphyry and contains visible gold. The vein, from which irregular quartz stringers branch, overlies an anticlinal mass of greywacke.

The West Ore Zone, 1,400 feet west of the North Ore Zone, comprises lenses of sulphides in iron formation that has been drag folded, and dips north at 68°. As in the North Ore Zone, the sulphides have selectively replaced the softer sheared portions of the iron formation. Several quartz veins containing free gold were found in the greywacke immediately south of the iron formation. A single specimen, part of a drill core, is composed almost entirely of pyrrhotite, but contains considerable free gold.

Production figures show that, in the year ending September 30, 1941, 240,098 tons of ore were milled for an average recovery of $9.52.

Mineral Paragenesis (Fig. 15). The mineralogy at the MacLeod-Cockshutt mine is similar to that at Hard Rock. Ten metallic minerals were identified, and three minerals were tentatively identified as tellurides. Pyrite is the most abundant sulphide as arsenopyrite is less common than at Hard Rock. Free gold was found in more than half the polished sections and in some of the hand specimens.

The mineral sequences have been compiled for each of the ore zones in the following tables:

TABLE 3.

210 QUARTZ VEIN.

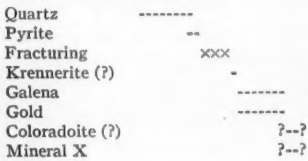


TABLE 4.

NORTH ORE ZONE.

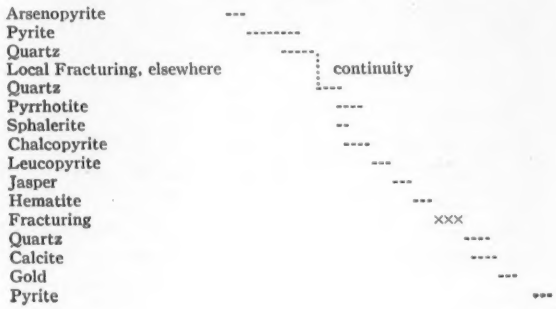


TABLE 5.

SOUTH ORE ZONE.

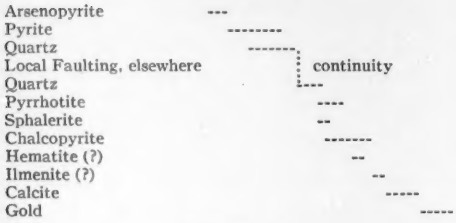


TABLE 6.

WEST ORE ZONE.

Table 3. The specimens from this high-grade vein contain spectacular amounts of free gold. The sections are composed almost entirely of gold, galena, and quartz with very minor amounts of pyrite and several minerals identified as tellurides.

Quartz was the first mineral to crystallize and in almost all cases is automorphic against pyrite, the second mineral. Pyrite is represented by only a few small grains, which rarely show crystal faces against the quartz. Quartz and pyrite were fractured during a period of movement, and the fractures filled with galena and gold. The walls of the fractures are generally ragged, due to this replacement. The relation of gold and galena to one another indicates they were contemporaneous; as many cases of gold conform to galena as the reverse. A lath-shaped mineral identified as krennerite (?) which was found in the galena is due to prior crystallization or automorphic replacement. Galena and gold are replaced by coloradoite (?) and an undetermined mineral X but the relations of these two minerals to one another are unknown.

Table 4. In all specimens from this zone arsenopyrite occurs as euhedral crystals, some of which are fractured. Crystals and masses of pyrite conform to arsenopyrite, and to a slight extent, to quartz. In general, quartz conforms to pyrite, but there is a little overlap in the relationship. Some sections contain arsenopyrite, pyrite, and quartz which are fractured; in other sections no fracturing of this period is indicated, but the deposition of quartz continued. Pyrrhotite, sphalerite, and chalcopyrite occur in much the same mutual relationship as in the Hard Rock ores, but are somewhat overlapped by quartz, which rarely conforms to these minor sulphides. Leucopyrite occurs as minute prisms and dendrites which conform to and replace those minerals which precede it in the table. Jasper and hematite were not observed in contact with leucopyrite, but it is probable that they are later. Both occur in fractures in fairly massive pyrite (Fig. 15) which contains blebs of the minor sulphides. Jasper was deposited first; hematite conforms to its outlines and is found in the middle part of the fracture fillings. Later fractures are filled with quartz and calcite which are in overlap relationship; most of the calcite conforms to the quartz, but the reverse is not uncommon. Gold was probably brought in by these late solutions. It conforms to calcite and all other minerals.

The late pyrite noted in the table occurs as drusy coatings in fractures in some of the hand specimens.

Table 5. Except for a greater overlap of quartz and pyrite, the sequence of minerals in this zone is the same as that in the North Ore Zone, as far as the end of the minor sulphides mineralization. In one specimen chalcopyrite is the dominant sulphide. Hematite, which is later than pyrrhotite in most places, conforms to chalcopyrite, but there is evidence that it is partially replaced by chalcopyrite in other specimens. A mineral identified as ilmenite conforms to every other mineral except calcite and gold. Calcite conforms to all those minerals which precede it in the table, but presents crystal faces to the minute grains of gold which was apparently the latest mineral.

Table 6. Only one polished section was available; it is noteworthy for the high proportion of pyrrhotite, and lack of arsenopyrite. Quartz was the first mineral to crystallize, closely followed by pyrite. In most cases quartz is automorphic against pyrite, but the reverse is not unusual. Pyrrhotite and sphalerite were deposited together following pyrite. Chalcopyrite overlaps sphalerite and is automorphic against some of the pyrrhotite. Deposition of pyrrhotite probably continued through rather a long period. Leucopyrite is fairly closely related to pyrrhotite, to which it conforms and which in part it replaces. Calcite conforms to all the minerals which precede it in the table, but presents its own crystal outlines against gold. As before, gold is the last mineral to be deposited; it was deposited in open spaces and also has replaced some of the sulphides.

Little Long Lac Gold Mines Limited.

General Geology. The geology and ore deposits of the Little Long Lac mine have been the subject of several papers by E. L. Bruce [9, 10, 11] and by E. L. Bruce and W. Samuel.[12]

The rocks in the vicinity of the mine are similar to those of the Hard Rock and MacLeod-Cockshutt mines, comprising basic lavas, sediments, dioritic intrusives, and lamprophyric dikes. No albitite porphyries have yet been found near the orebodies at Little Long Lac.

The "Keewatin-type" basic lavas, which dip steeply southward, lie about one-half mile north of the mine shaft. They are not likely to be encountered underground because the veins are almost vertical.

[9] Bruce, E. L.: Little Long Lac Gold Area. Ont. Dept. Mines, 44, pt. 3: 33–43, 1935.

[10] ——: New developments in the Little Long Lac area. Ont. Dept. Mines, 45, pt. 2: 124–125, 1936.

[11] ——: Structural relations of some gold deposits between Lake Nipigon and Long Lake, Ontario. Econ. Geol., 34: 362–365, 1939.

[12] Bruce, E. L. and Samuel, W.: Geology of the Little Long Lac Mine. Econ. Geol., 32: 318–334, 1937.

The "Timiskaming-type" sediments consist of arkoses, greywackes, iron formation, and conglomerate, all of which are lenticular, partly a relict primary structure, and partly a result of folding. The arkoses contain feldspar in excess of the 25 per cent requisite to the name, but quartz is also abundant. The rock is easily distinguished by its granular texture and gray color on fresh fracture surfaces. Both underlying and overlying the arkose are beds of greywacke, finer grained and darker in color than the arkose. In general, the greywacke is massive and contains considerable chlorite, but parts of the overlying layer are somewhat slaty. The iron formation bears the same relation to the greywacke as at Hard Rock and MacLeod-Cockshutt, all gradations being noted between greywacke with hematite and magnetite lenses and the more characteristic banded iron formation. This rock forms two discontinuous bands in the lower part of the sedimentary series. Conglomerate does not outcrop near the mine, but some beds have been encountered underground.

A mass of diorite outcrops about 600 feet south of the ore zone. Underground developments have shown a narrow lamprophyric dike altered to calcite. Outcropping a little more than a mile west of the mine is a narrow diabase dike, trending north-south.

The major synclinal structure of the area of which Little Long Lac is a part is complicated by a large drag fold. The beds, which normally strike almost east-west, are dragged northward about 3,000 feet and then resume their original strike. Shear zones developed in the arkose after the folding strike east-west or just north of east, parallel to the slightly curved axial plane of the drag fold. Measurements show that there is a westward plunge of about 50° to the minor structure. During the folding period the iron formation underwent considerable thickening and thinning and developed intricate plications. At the same time the greywacke developed a rather uniform schistosity, whereas the arkose yielded with the formation of the shear zones.

The Orebodies. The orebodies are confined to shear zones in the arkose beds. The main lode, which strikes nearly east-west and dips steeply to the south, lies about 80 feet south of the axial

plane of the fold. In general, a single lode may be considered to be composed of two quartz veins 3 to 4 inches wide, separated by a sheared zone 40 to 50 inches wide containing numerous veinlets and stringers of quartz. The quartz veins are extremely variable in thickness, but remarkably continuous in length. Some veinlets only a fraction of an inch wide have been traced several feet. Although the veinlets ultimately pinch out, it has been found that others begin along parallel shear planes where the first veinlets end, thus maintaining a fairly constant proportion of quartz.

There are two main zones about fifty feet apart. Linking the two zones are veins which branch off from one main zone and join the other in a reverse curve. These veins plunge eastward in a direction almost perpendicular to that of the drag fold and may represent the original bedding. From the 11th to the 16th levels, the main vein is displaced southward by faulting a distance of about 150 feet.

In the typical lode described above, each of the two quartz veins may assay as high as 20 oz. of gold, but the average is 3 to 5 oz.; the intermediate zone, carrying sulphides, averages about 0.15 oz. It has proved economical to mine out the entire width which then averages about 0.5 oz. gold per ton. The main lode is 800 to 1,200 feet in length and has been developed to 2,200 feet with sixteen levels. During 1941, an internal shaft was sunk from the 16th level in order to open up four new levels. Lateral development is progressing and the vein has been reached on the 17th level. Production figures for 1941 show tonnage milled as 118,-332 for a recovery of $13.82 per ton. Ore reserves at the end of 1941 were estimated at 440,000 tons averaging $15.67 per ton in gold.

Mineral Paragenesis. In the examination of polished sections from this mine, nine metallic minerals were identified and a tenth tentatively identified. Arsenopyrite and pyrite are again the most abundant sulphides, occurring in about equal proportions. Free gold was observed in about half the sections examined; it was also observed in many of the hand specimens.

Bruce [13] outlined the following table of paragenesis in his study of this mine.

An important difference between this table and that of the writer, which is given below, is in the respective positions of the metallic and the nonmetallic minerals. In addition to the minerals listed in his diagram, Doctor Bruce identified stibnite and suggested that bismuthinite also might be present.

Ellis Thomson [14] examined polished sections of Little Long Lac ore and found limonite, hematite, magnetite, and berthierite in addition to several other minerals which were also identified in the present investigation. None of these four minerals was identified in any of the sections available to the writer.

The following table presents the sequence of minerals at Little Long Lac as observed in the present work:

TABLE 7.

LITTLE LONG LAC.

Discussion of the Table. In almost every specimen, arsenopyrite was the first mineral to crystallize, as shown by the pre-

[13] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., p. 40.

[14] Thomson, Ellis: Mineralization of the Little Long Lac and Sturgeon River Areas. Toronto Univ. Studies, Geol. Ser., 38: 38–41, 1935.

ponderance of euhedral over anhedral grains. Whether the grains are diamond or lath-shaped in outline depends upon their orientation in the polished section. The overlap relationship of pyrite and arsenopyrite is suggested in a few places where pyrite is automorphic against arsenopyrite. In some specimens, the arsenopyrite and pyrite are fractured, the cracks being filled and their walls partially replaced by metallic and nonmetallic minerals. In other specimens, no period of fracturing is apparent and quartz was deposited in overlap relationship with pyrite. Quartz always conforms to the crystal outlines of arsenopyrite, or replaces it, and with the exception noted above, is later than pyrite.

The position of the mineral temporarily identified as ilmenite is not very certain. It is probably contemporaneous with the last of the early quartz. Pyrrhotite, sphalerite, and chalcopyrite occur in very much the same relationship to one another as in the Hard Rock ores. They are all later than quartz, and occur as grains and blebs in the gangue, as well as in the major sulphides. Chalcopyrite was seen in several sections filling fractures in pyrite and arsenopyrite, and slightly replacing these minerals. Galena was found in a few specimens where it was automorphic against some chalcopyrite and sphalerite. Mutual boundaries between galena and these two minerals in other places suggest overlap. While leucopyrite was not observed in contact with chalcopyrite, it is later than pyrrhotite, which it sometimes replaces. The major and minor sulphides are automorphic against, or sometimes replaced by, bournonite, but no contacts of leucopyrite and bournonite were seen. Gray copper occurs as small blebs and grains which have mutual boundaries with some of the bournonite. It also occurs as replacement and space-filling blebs in the major sulphides. The mineral identified as ankerite conforms to the outlines of all the minerals which precede it in the table; a few replacement contacts were also observed. Although it is generally automorphic against gold, there were several places where it conformed to the gold outlines, indicating overlap of the two minerals. A second period of fracturing is suggested by the fractures in the quartz and ankerite of the sections. Fractured gold was not observed, probably be-

cause of the small size of the gold grains. The fractures were filled with a quartz-calcite mixture in which quartz crystallized first. The presence of pyrite crystals on the crystals of calcite in one of the hand specimens indicates the late pyrite shown in the table. A specimen of Little Long Lac ore recently sent to the writer contains the mineral scheelite. It was not possible to determine its age relations with all the other minerals, but the fact that it occurs in quartz veins and is cut by later quartz veinlets indicates that it is older than the later quartz. Information supplied by W. Samuel states that the mineral occurs as bunches and blebs in the main vein and in 409 vein. It also occurs as a veining mineral in the rock adjacent to the quartz veins. In 409 vein scheelite averages about three or four pounds per ton; the general average for the two occurrences is somewhat lower, about two pounds per ton.

Magnet Consolidated Mines Limited.

General Geology. The rocks in the vicinity of the mine comprise sediments, intrusive porphyries, and diabase. There are no outcrops in the immediate vicinity; bedrock is covered by a heavy overburden about fifty feet in depth.

The sediments consist of greywacke, conglomerate, and iron formation. The shaft was sunk in a wide band of greywacke. About 100 feet south of the shaft, the greywacke becomes fine grained and then makes a sharp contact with a black slaty rock containing small relatively sparse pebbles which are all highly carbonatized. This conglomerate, like other slaty horizons, is greatly thickened near the axes of minor folds and varies from 30 to 150 feet in thickness. To its south is a band of sericitic quartzite, probably a sericitized relatively coarse band of greywacke. This band is about 100 feet wide and is succeeded on the south by more greywacke. About 400 feet north of the shaft, a pinching and swelling band of contorted iron formation is indicated by diamond drill intersections and dip-needle surveys. A very minor discontinuous band of iron formation strikes slightly to the right of the vein. It crosses the vein at about the center of the ore zone, which is characteristically heavier in sulphides but leaner at the intersection.

About one-third of a mile northwest of the shaft is a body of porphyry which is probably the same as that on the Bankfield property. It should, therefore, be more correctly termed albitite porphyry. A few hundred feet north of this is a mass of diorite or dioritic porphyry. Recent developments have disclosed the presence of a mass of diorite in the shaft below the 1080-foot level. Several narrow but apparently persistent diorite dikes occur to the north of the vein on the 2nd level and a relatively small dike-like mass of porphyry has been indicated by drilling at about 300 yards northwest of the shaft. A diabase dike about 12 feet wide cuts across the vein almost at right angles, dipping steeply to the west. Nine hundred feet east of the shaft there are several north trending diabase dikes. One of these dikes, about 60 feet wide, may possibly mark a fault which has displaced the east continuation of the band of arkose about 170 feet south. This displacement, however, may be due to folding.

The Orebodies. The ore at Magnet Consolidated occurs in two parallel quartz veins which are bordered by narrow zones of sericitization. Intense sericitization colors the rock greenish buff for an inch or less from the quartz beyond which, for a few inches or more, the rock is usually perceptibly lighter colored than is the normal greywacke. In some instances a narrow zone of heavy sulphides continues along the strike beyond where the quartz pinches out. Although of good grade, this material is usually too narrow to mine. There are no indications of shearing or faulting in the country rock along the strike of these zones. The width of the veins in the upper levels of the mine averages about three feet, and their trend is N75° W with a dip of about 80° to the south. In the lower levels, the veins average twelve to eighteen inches but the ore shoot is considerably longer than in the higher levels. The dip of the veins here varies from steeply south to steeply north. The veins are developed in medium grained greywacke which has been dragged into a well-developed fold plunging at about 45° to the west. The orebodies rake to the west at about the same angle.

The average ore on the lower levels in the mine contains a high proportion of arsenopyrite. This ore is quite distinct from the

quartz with gold and galena—high grade material—which is particularly abundant in small structures resembling folds in the veins. These structures, according to P. C. Benedict[15] occur in places where the greywacke shows no minor folding. One of the best developed of these plunges east at about 45°, a direction just opposite that of the drag folding. Benedict believes these structures to be "due to the quartz locally following the tension element of the shear pattern for a very few feet."

The main ore shoot has been developed down to the 1080-foot level, where it is 850 feet in length. Drifting on the 1380- and the 1730-foot levels has disclosed continuation of the orebodies. During 1941, a short shoot of marginal ore was developed in a small vein lying about 600 feet north of the main ore shoot. Production figures for 1941 show 47,731 tons mined. The average recovery, after sorting, was 0.556 oz. per ton.

Mineral Paragenesis (Figs. 6, 12, 13). The mineralogy of the ores from this mine is not complex. Seven metallic minerals were identified, the chief of which is arsenopyrite. Pyrite is present in somewhat minor amount. Free gold was observed in many of the polished sections and hand specimens. It was present in spectacular amount in one specimen from the drag fold on the 1080-foot level.

The following table has been drawn up to represent the sequence of mineralization:

TABLE 8.

MAGNET CONSOLIDATED.

Arsenopyrite	--------
Pyrite	----
Fracturing	xxx
Quartz	-------
Pyrrhotite	---
Chalcopyrite	-----
Leucopyrite	----
Calcite	------
Galena	----
Gold	----
Fracturing	xxx
Quartz	---
Calcite	---

Discussion of the Table. Arsenopyrite, as in many of the other mines, was the first mineral to crystallize. The characteristic

[15] Benedict, P. C.: Personal communication.

euhedral outlines are supplanted in some sections by ragged borders due to replacement of arsenopyrite by later minerals. Pyrite usually conforms to arsenopyrite, but one specimen was examined in which pyrite was, in part, the earlier of the two. Since this relationship was observed in only one section, it is indicated by only a slight overlap in the table. In most of the sections, arsenopyrite and pyrite have been fractured, the fractures being filled with metallic or nonmetallic minerals. In other sections there is no evidence of this fracturing and quartz was deposited directly after the pyrite. In all cases quartz is definitely later than the pyrite and conforms to, or replaces, both pyrite and arsenopyrite. Pyrrhotite conforms to the major sulphides and to quartz. It occurs as replacement and space-filling blebs in the major sulphides and in some sections fills cracks. Chalcopyrite occurs in overlap relationship with pyrrhotite; in most places it conforms to pyrrhotite (Fig. 13), but their presence in segmented veinlets in fractured arsenopyrite suggests they are contemporaneous. In a few instances the contacts were such as to suggest that chalcopyrite was the first to crystallize.

Leucopyrite (Fig. 12) was observed in contact with pyrite, pyrrhotite and arsenopyrite. It is distinctly later than pyrrhotite and is probably later than chalcopyrite, although the contact was not observed. Calcite conforms to the tiny prisms and dendrites of leucopyrite. Crystal faces of chalcopyrite and pyrrhotite against calcite also were observed. Galena and gold are essentially contemporaneous (Fig. 6), an equal number of crystal faces of each against the other being found in the sections. Their contacts, if not those of crystal faces, are entire and rounded, rather than ragged replacement contacts. The presence of gold along cleavage planes in calcite in one hand specimen, and the conformity of both galena and gold to calcite in the polished sections indicate their respective ages. One of the hand specimens shows a veinlet of quartz and calcite cutting across the other minerals. It is a fracture filling because the opposite walls match perfectly. Its segmented character indicates quartz and calcite are contemporaneous.

Bankfield Consolidated Mines Limited.

General Geology. The geology and ore deposits of the Bankfield mine have been the subject of papers by A. W. Johnson [16] and E. L. Bruce.[17, 18, 19]

The rocks in the vicinity of this mine, continuous with those at Tombill, comprise sediments, albitite porphyry, and diorite. The sediments include greywacke, slaty greywacke, conglomerate, and iron formation, of which the greywackes and argillite-like greywackes are the most important. The beds strike almost east-west dipping steeply to the south, but have been fractured and sheared by later deformation. Some of the coarser greywacke has been silicified by solutions from the feldspar porphyry masses.

The sediments are intruded by masses of diorite and albitite porphyry. Diorite occurs as dikes and irregular masses. Some of the more regular masses may actually represent recrystallized volcanics interbedded with the sediments. The albitite porphyry occurs in dikes and elongated lenticular masses striking east-west and dipping steeply to the south. These porphyry masses have been somewhat fractured by the movements which sheared the sediments.

The Orebodies. The original work was done on the North zone which contained some gold but no commercial ore. The entire production of the mine has come from the South zone.

The South zone is continuous with the Tombill orebody, consisting, therefore, of a sheared and fractured zone at the contact of albitite porphyry, greywackes, and lean iron formation. Mineralization is fairly heavy, gold values and sulphides being disseminated in irregular lenses in the sheared rock and in the quartz-filled fractures. One section of the South zone strikes east-west and dips south at about 75° over a length of 275 feet up to the

[16] Johnson, A. W.: Geology and Ore Deposits of the Bankfield Gold Mine. (Unpublished M.Sc. thesis, Dept. of Geol. Queen's University, 1935.)

[17] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., pp. 46–50.

[18] ——: New developments in the Little Long Lac Gold Area. Op. cit., pp. 135–140.

[19] ——: Structural Relations of some gold deposits between Lake Nipigon and Long Lake, Ontario. Op. cit., p. 361.

east boundary of the Tombill property. The types of ore in this section have been discussed by Doctor Bruce.[20]

The other section in the South zone lies to the south of the Tombill property. The Tombill vein dips into the Bankfield below the 525-foot level, and has been developed by a winze sunk from that level about 1,700 feet west of the main shaft. Production figures for the eleven months ending October 31, 1941, show 36,072 tons milled at an average recovery of $6.82 per ton.

Mineral Paragenesis (Figs. 4, 8, 16, 17, 18). The Bankfield mine is the only one in this area for which supergene minerals were recorded. Eight hypogene and three supergene metallic minerals were identified in the polished sections. Free gold was observed in most of the sections and in a few hand specimens.

In his study of the ores, Johnson [21] found three periods of fracturing marking the intervals between deposition of arsenopyrite, pyrite, ilmenite, and pyrrhotite and chalcopyrite, respectively. He found no time break between pyrrhotite and chalcopyrite. The present work indicates two periods of fracturing; one in the middle of mineralization, the other at the end, during which fissures were formed and filled with quartz and calcite.

The following table illustrates the sequence of minerals of the Bankfield ores.

TABLE 9.

BANKFIELD

Arsenopyrite	------
Pyrite	--------
Fracturing	xxx
Quartz	-----
Ilmenite	--
Pyrrhotite	----
Sphalerite	---
Chalcopyrite	-----
Grey Copper	-
Calcite	----
Gold	---
Fracturing	xxx
Quartz	---
Calcite	---
Chalcocite }	--
Limonite } Supergene	---
Malachite }	---
Calcite }	---

[20] Bruce, E. L.: New developments in the Little Long Lac Area. Op. cit., pp. 138–140.

[21] Johnson: Op. cit., p. 23.

Discussion of the Table. Arsenopyrite is rather subordinate in quantity to pyrite, but in many cases is the earlier of the two minerals. Skeleton crystals are common in which one or more faces are not developed perfectly. Pyrite presents its own crystal outlines to all other minerals (Fig. 4) sometimes including arsenopyrite. Both pyrite and arsenopyrite are fractured, particularly the larger crystals. Small perfect crystals are considered to be of the same age as the larger but fractured crystals. Quartz was deposited immediately after the period of fracturing; many of the fractures in the major sulphides have been sealed with quartz or minor metallics. Ilmenite (Fig. 16) conforms to quartz, but itself is automorphic against, or replaced by, the later minerals. Pyrrhotite, sphalerite, and chalcopyrite are related to one another in the same way as in most of the other mines, and are later than ilmenite. Gray copper is overlapped by chalcopyrite, but is later than pyrrhotite and sphalerite. It occurs as inclusions in pyrite in one polished section, where it appears to be later than pyrrhotite but contemporaneous with some of the chalcopyrite. Early calcite conforms to chalcopyrite and all the other minerals with the exception of gold. The exact position of gold in the sequence is not definite; it may be earlier than the second fracturing, or it may have been brought in by the solutions which followed that fracturing. One very high grade specimen contains considerable free gold which occurs as blebs and veinlets in quartz and pyrite (Fig. 8). The veinlets are of the replacement type; the blebs are commonly outlined by smooth crystal faces of quartz or pyrite. None of the sections examined shows the second period of fracturing. Many of the hand specimens, however, are cut by veinlets of quartz and calcite in which the calcite is located medially, conforming to the crystal outlines of quartz.

The supergene minerals are interesting in their relationships. Pyrite and chalcopyrite are intricately laced with networks of chalcocite and limonite veinlets showing the abrupt ends characteristic of replacement (Fig. 18). In these ribbon-like veinlets chalcocite lies nearest the primary mineral. Limonite forms

a narrow strip down the middle of the veinlets; it is later than the chalcocite. Malachite (Fig. 17) was found in only one part, where it forms a cluster of fine green needles radiating outward from the limonite rims of a chalcopyrite grain. Close to this group is another cluster of brown needles of limonite or goethite. The similarity of occurrence of the two clusters suggests an overlap in the relationship between the two minerals. Calcite has filled the interstices between the needles of malachite; their relative ages are thus indicated.

Tombill Gold Mines Limited.

General Geology. The rocks in the vicinity of the Tombill mine are covered by about ninety feet of glacial drift. Those encountered in the underground workings are the same as those in the adjoining Bankfield mine.

Greywacke occurs in parallel bands and lenses striking N72° W, and dipping steeply to the south. Several varieties have been mapped, including chloritic and arkosic greywackes. The sediments have been intruded by diorite and by quartz-feldspar porphyry. The latter is a continuation of the Bankfield rocks identified by E. L. Bruce [22] as an albitite porphyry. It occurs as elongated lenticular masses in the diorite south of the vein and in the greywacke to the north. Where the intrusive character of the diorite is in doubt, it is possible that the rock is actually recrystallized volcanic material. The Tombill shaft is sunk in arkosic greywacke 75 feet north of the vein.

The Orebodies. There are two ore zones at Tombill, the North and the South. The South zone is a continuation of the main Bankfield ore zone, silicified at the contact of the diorite and the sediments and probably represents silicified greywacke or arkosic greywacke. This is the only zone in production. Underground developments over a length of 2,000 feet have disclosed six blocks of ore. The steep southerly dip carries the vein into the Bank-

[22] Bruce, E. L.: New developments in the Little Long Lac Area. Op. cit., pp. 137–138.

field property to the south below the 600-foot level. The annual report dated March 1, 1941, disclosed that the South ore zone has been fully prospected and that no further ore is expected. A fairly wide siliceous zone 300 feet north of the shaft is lightly mineralized but has yielded no ore.

The North ore zone lies about 2,000 feet north of the South, and contains a twelve-inch band of iron formation interbedded with greywacke, which is irregularly folded and carries low values. The possible ore of the North zone is associated with a narrow silicified quartz feldspar dike carrying some visible gold and scheelite but not in commercial quantities. A crosscut extending northerly from the second level station was driven more than 2,000 feet, but the results of the exploration work and drilling, including 430 feet of drifting, disclosed no ore under the present conditions. Some of the material was run through the mill, but proved to be too low grade.

The orebodies are generally lenticular in shape and their underground structure is not complex. Numerous minor faults have been encountered in the South ore zone. Most of these faults trend northwest and dip southwest. The most important fault dips about 42° to the southwest, the throw along it amounting to about 40 feet. The west end of the vein has been displaced to the north relative to the eastern extension.

During 1941, a total of 46,956 tons of ore was milled for a recovery of $10.81 per ton. Reserves at the end of 1941 were expected to be exhausted about September, 1942.

The property of Elmos Gold Mines Limited, lying three miles to the east adjacent to Little Long Lac and MacLeod-Cockshutt, has been acquired and is being dewatered. Ore from this property will be milled when the Tombill orebodies are exhausted.

Mineral Paragenesis (Figs. 5, 9, 10, 14). Polished sections permitted the identification of seven metallic minerals. Free gold was observed in almost all the specimens, two of the hand specimens being very high grade. One specimen contains a very high proportion of chalcopyrite, but pyrite is the conspicuous sulphide in the other sections.

The following table shows the sequence of minerals at Tombill:

TABLE 10.

TOMBILL.

Arsenopyrite	------
Pyrite	--------
Fracturing	xxx
Quartz	------
Sphalerite	--
Chalcopyrite	----
Ilmenite	---
Graphite	---
Fracturing	xxx
Pyrite	---
Quartz	---
Calcite	---
Gold	----

Discussion of the Table. Arsenopyrite, although not present in every section, was the first mineral to crystallize. It is euhedral against the other minerals except where it has been replaced. Pyrite in general is more abundant than arsenopyrite to which it conforms. Both arsenopyrite and pyrite were fractured during a period of movement which followed the crystallization of pyrite and preceded that of quartz (Fig. 5). The fractures in pyrite and arsenopyrite are filled with quartz and metallic minerals. Quartz conforms to the major sulphides, but presents its own crystal outlines to the other minerals (Fig. 10). The Tombill ores are noteworthy for the lack of pyrrhotite in all the sections examined by the writer. Sphalerite and chalcopyrite are in overlap relationship (Fig. 14); both are conformable to quartz. Chalcopyrite filled a few cracks in the fractured sulphides and apparently had a longer period of deposition than sphalerite. Conforming to, and partially replacing, chalcopyrite are irregular grains of ilmenite. The relations of ilmenite and graphite were not observed, but graphite is distinctly later than the chalcopyrite. Some graphite may have been developed during the second period of movement which caused fracturing of the earlier minerals.

The second period of fracturing is best shown in the hand specimens, where the earlier quartz is transversed by fracture veinlets of contemporaneous quartz and calcite. The polished sections

show tiny euhedra of pyrite in some of these veinlets; it is earlier than the quartz or calcite. Gold was apparently introduced after the second fracturing. It occurs as fracture fillings in the early quartz and is later than the chalcopyrite with which it is sometimes associated. In the high grade sections, gold occurs with pyrite and arsenopyrite, sometimes replacing them, in other places surrounding euhedra of the sulphides with no apparent action on them (Fig. 9).

Jellicoe Mines (1939) Limited.

General Geology. The ore deposits at the Jellicoe mine are associated with sediments and intrusive porphyries. Bedrock in the vicinity of the mine is covered with a heavy overburden of glacial drift about 50 feet thick.

The sediments comprise greywackes grading into "arkoses," [23] and slaty greywackes, some of which carry considerable chlorite. The shaft is located in a broad belt of chloritic greywacke striking just north of west. A 400 foot band of "arkose" which lies 50 feet south of the shaft contains the Main Zone orebodies. About 900 feet north of the shaft is a narrow band of iron formation; a second band of iron formation about half a mile south of the shaft is believed to be a different band.

Just north of the shaft a narrow band of rock, which parallels the trend of the greywacke, has been identified as a diorite sill. The difficulty of distinguishing between intrusive diorite and recrystallized interbedded volcanic material has been noted elsewhere. It is possible that the so-called diorite is such an interbedded volcanic rock.

About 700 feet north of the shaft, a band of rock trends just north of west; it is known at the mine as the "Quartz-feldspar Marker." A similar rock type on the adjacent Tombill property is called quartz-feldspar prophyry. Specimens of these rocks were found to be very similar to the albite porphyry at the Bank-

[23] The term "arkose" as used at this mine is applied to a light-colored rock which may actually be an altered and bleached greywacke.

field mine. The "Quartz-feldspar Marker" is an almost vertical dike cutting across the greywacke at a small angle.

An irregular mass of porphyry associated with conglomerate and chloritic greywacke extends into the property about one mile south of the Jellicoe shaft.

The Orebodies. The Main Zone orebodies are confined to vein quartz and silicified and brecciated zones in the band of arkose just south of the shaft. This band dips to the southwest at 75° to 80° along its northwest strike. Two sections, the eastern and western, of the Main Zone have been developed.

The arkose of the Eastern section is partially silicified and differs from the ore shoots only in its lesser degree of silicification. Free gold was observed only where there is almost 100 per cent quartz. The main structure, as determined by G. C. McCartney,[24] Consulting Geologist for the mine, is in the form of a flat "S"; this "S" appears both in plan and in section. The ore of the first level main break forms the body of the "S." On the second level small, flatly westward pitching veins appear as large drags when viewed in plan. A feature of these veins is the variation in the development of vein quartz; in some places, general zones of silification take the place of vein quartz. All veins and ore occurrences appear to follow crush or fault zones in the arkose. The tailing out ore zone is displaced by a fault about 200 feet west of the shaft. This fault strikes just east of north and dips steeply to the southwest. Beds on the west of the fault are displaced northward about 200 feet relative to the same beds on the east of the fault.

The so-called Western section of the Main Zone was thoroughly diamond drilled from the surface. During the first seven months of 1940 a 2,000 foot drift was run on the 500-foot level from the Eastern section. Further drilling from this location failed to prove anything approaching an economic deposit. Operations by the present company were discontinued permanently on this property in August, 1940.

A total of almost 14,000 tons of ore from the Eastern section

[24] McCartney, G. C.: Private report to the directors.

was treated at the Magnet and Bankfield mills. The grade averaged almost 0.4 oz of gold per ton.

Mineral Paragenesis. The mineralogy at the Jellicoe mine is not complicated. Eight metallic minerals were identified. Arsenopyrite is more abundant than pyrite. Free gold was observed in more than half the polished sections, and in a few of the hand specimens.

The sections and hand specimens indicate only one, a rather late, period of fracturing. The composite table illustrating the mineral sequence is as follows:

TABLE 11.

JELLICOE.

Arsenopyrite	--------
Pyrite	---
Quartz	-------
Pyrrhotite	---
Sphalerite	--
Chalcopyrite	-----
Ilmenite	---
Stibnite	?--?
Fracturing	xxx
Quartz	------
Calcite	------
Gold	----
Pyrite (drusy)	---

Discussion of the Table. Arsenopyrite was the first mineral to crystallize and in every section its crystal outlines were exhibited against all others except where it has been partially replaced. Pyrite conforms to, or replaces, arsenopyrite, but in turn is automorphic against the later minerals. A period of deposition of quartz interrupted the sequence of sulphide mineralization. The quartz was followed by pyrrhotite, sphalerite, and chalcopyrite in the order in which they are found in most of the other mines of the area. The chalcopyrite is fairly abundant as replacement veinlets and blebs in the gangue and in the major sulphides. A hard gray mineral with the characteristics of ilmenite was observed in several sections where it follows the minor sulphides, and in contact with chalcopyrite which it had partially replaced. Stibnite was identified in only one section. It was not seen in

contact with ilmenite, but the character of its contact with chalcopyrite indicates that it is the later of the two.

The evidence for a period of fracturing was observed in a single section where a barren quartz-calcite veinlet cuts the sulphides and quartz. Similar veinlets were seen in several hand specimens. In these veinlets quartz crystallized prior to calcite. In some sections, calcite was deposited from fracture-filling solutions which penetrated beyond the fissures. Gold was carried in by these solutions and in several places conforms to the calcite. In unfractured sections, the gold fills spaces between the earlier minerals. Drusy pyrite was observed in some of the hand specimens, where it was deposited in fractures on the second generation of quartz.

SUMMARY AND CONCLUSIONS.

General Paragenesis.

In the early days of development in the Little Long Lac area, Ellis Thomson [25] examined a collection of specimens. As a result of his study, Thomson outlined a general order of mineral deposition as follows:

1. Quartz, pyrite, arsenopyrite, magnetite.
2. Quartz, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, carbonate.
3. Carbonate, pyrite, berthierite, sphalerite.
4. Galena, gold, tetrahedrite.
5. Limonite.

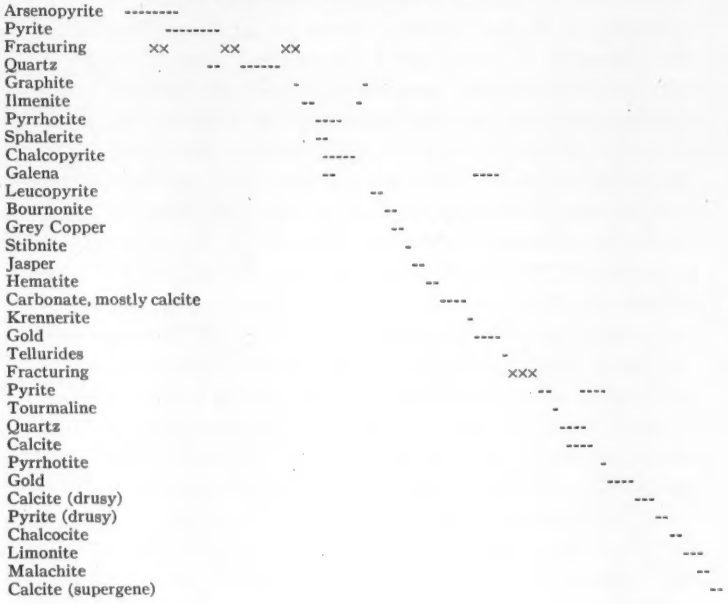
In the course of the present work, the writer found no magnetite which showed evidence of being introduced with the mineralizing solutions. Considerable magnetite was found in the iron formation ores from Hard Rock and MacLeod-Cockshutt, but it is not related to the sulphides which have replaced parts of the iron formation. Other differences from the earlier work are apparent in the table which follows. This table represents a generalization

[25] Thomson: Op. cit., pp. 38–41.

of the broader areal relations together with as much detail as could be included. Many of the eleven individual tables show considerable differences, but certain features of each appear to be characteristic of the area as a whole.

TABLE 12.

GENERAL SEQUENCE OF MINERALS.



Discussion of the Table. The order of deposition of the first three, and most abundant, minerals is almost everywhere the same (Figs. 1, 2, 4), but the arsenopyrite does not occur in all the orebodies. During this period of deposition, there was considerable movement which resulted in fracturing of the mineral or minerals already crystallized. The time of fracturing varies from place to place; generally two minerals were fractured, but in places only

one or all three minerals were fractured (Figs. 3, 5, 7). In some cases, this early period of fracturing is lacking.

In almost every mine, pyrrhotite, sphalerite and chalcopyrite occur as blebs and veinlets in the major sulphides and quartz (Fig. 11). Their order of deposition and mutual relationships are the same in each place, even if one of the three is missing. Chalcopyrite and pyrrhotite are abundant locally (Figs. 10, 13), but sphalerite never forms a major part of the ores (Fig. 14). The relationships of graphite and ilmenite to each other and to the other minerals are not nearly as constant as those of the above three minerals. Neither graphite nor ilmenite is abundant in any section. Graphite was observed in only two mines; in one it was deposited during movements which followed the deposition of quartz, in the other it is distinctly later than chalcopyrite and probably later than ilmenite. Ilmenite was observed in specimens from seven different orebodies (Fig. 16); in three of these it precedes pyrrhotite, in the other four it is later than chalcopyrite. Galena, also, does not show constant relationships. It was identified in sections from four orebodies; in two of these it occurs with pyrrhotite, sphalerite and chalcopyrite in overlap relationship, in the other two it is later than chalcopyrite and contemporaneous with the early gold (Fig. 6). In the latter cases, galena forms a fairly high proportion of the sections as distinct from its minor development when closely associated with sphalerite.

Stibnite, leucopyrite (Fig. 12) and the sulpho-salts bournonite and gray copper are found locally and in very minor amount. Their respective ages are indicated in the table; everywhere they are later than chalcopyrite and earlier than gold or the later fracturing.

The jasper and hematite noted in the table occur in a section from the North Ore Zone at MacLeod-Cockshutt (Fig. 15). They are included here for the sake of completeness. In that section they are later than leucopyrite but earlier than the late fracturing. A second or late period of fracturing is indicated in specimens from almost every orebody. Preceding this fracturing,

but later than the sulpho-salts in many of the sections, is an early carbonate, generally calcite. At Little Long Lac, however, ankerite occurs. The carbonate may be followed by gold or by galena and gold. This early gold was observed in specimens from several of the mines. Where the second fracturing is lacking, gold is associated with the carbonate. The euhedral lath-shaped crystal embedded in galena, as observed in one section from the 210 Quartz Vein at MacLeod-Cockshutt, is possibly the telluride, krennerite. It is possible that it may be an automorphic replacement of the galena, but it is considered to be a prior crystallization. Other telluride-like minerals from the same location are apparently later than the gold and galena which they have partially replaced.

The fractures which have resulted from the late fracturing are filled with quartz and calcite. In these veinlets, the quartz began to crystallize first, but it is overlapped considerably by calcite. The veinlets commonly carry other minerals in addition to quartz and calcite. In sections from two orebodies pyrite was earlier than the late quartz; in another section it is later, overlapping the calcite deposition. Tourmaline in one section followed the pyrite but preceded quartz as shown in the table. Hand specimens from one orebody were cut by veinlets containing pyrrhotite with quartz, calcite and pyrite. The pyrrhotite is later than the calcite, but is contemporaneous with the later part of the pyrite. Gold is associated with many of these veinlets where it was deposited late in the sequence. Early and late gold were not found together in any one section. It is possible that both ages may be represented in some of the high grade specimens (Figs. 6, 7, 8, 9) but no criteria for distinguishing between them were found. It has been suggested that gold very closely associated with pyrite may have been in solid solution. Spectrographic investigations recently reported by P. E. Auger [26] indicate, however, that gold takes no part in the structure of pyrite crystals as solid solution, but rather occurs

[26] Auger, P. E.: Zoning and district variations of the minor elements in pyrite of Canadian gold deposits. Econ Geol., 36: 412, 1941.

as later replacements or fracture fillings. These findings are quite in accord with the observations made during the present study.

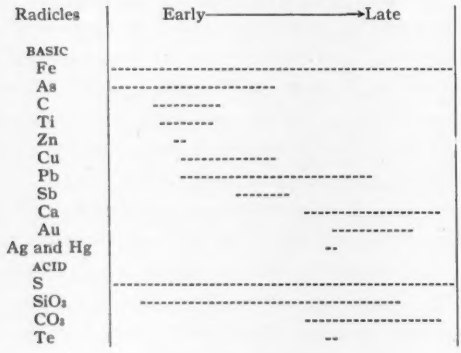
Drusy coatings of calcite and pyrite were observed in several hand specimens from different parts of the area. They probably represent the last slow percolations of the ore-bearing solutions.

The presence of chalcocite, limonite, malachite (Figs. 17, 18) and supergene calcite completes the table and indicates the action of downward enrichment and oxidation.

It is apparent from Table 12 that the mineralization in the Little Long Lac area is almost entirely hypogene. It has been considered advisable to express the sequence in terms of the radicles present in the mineralizing solutions as well as in terms of the combination of radicles as minerals. The sequence of radicles is presented in Table 13.

TABLE 13.

GENERAL SEQUENCE OF RADICLES.



Mineralogy.

The minerals which have been identified during the present study are listed in Table 14. Their position in the sequence of mineralization and the genetic conditions under which they were deposited are indicated.

TABLE 14.

	Hypogene			Supergene
	Early	Intermediate	Late	
Elements				
Graphite		R		
Gold		×	×	
Sulphides				
Arsenopyrite	×		R	
Chalcocite				R
Chalcopyrite		×		
Cubanite		R		
Galena		×		
Leucopyrite		×		
Pyrite	×		×	
Pyrrhotite		×	R	
Sphalerite		×		
Stibnite		R		
Sulpho-salts				
Bournonite		R		
Grey Copper		R		
Tellurides				
Coloradoite (?)		R		
Krennerite (?)		R		
Mineral X (?)		R		
Oxides				
Hematite		R		
Ilmenite		×		
Jasper		R		
Limonite				R
Quartz	×		×	
Carbonates				
Ankerite		R		
Calcite		×	×	R
Malachite				R
Tungstate				
Scheelite		R		

R indicates a rare mineral.

Character of the Ore Fluid.

Composition. The ore-bearing solutions contained the following elements: Ag, As, Au, C, Ca, Cu, Fe, Hg, Mg, Pb, Te, Ti, Si, S, Sb, W, Zn, and H_2O. Bruce [27] reports in the analysis of mill heads from the Little Long Lac mine, the occurrence of bismuth. No bismuth minerals were observed in the present work.

Wall rock alteration was not studied by the writer. Accord-

[27] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., p. 40.

ing to Bruce[28] wall rock alteration is not intense except for silicification in some zones, where there has been a considerable development of pyrite. Carbonatization has occurred in some places.

Morrow's[29] study at MacLeod-Cockshutt shows considerable alteration of greywacke and porphyry adjacent to the ore zones in the South orebody. He found a gain in K_2O, Al_2O_3, CaO, MgO, CO_2, H_2O, FeO, and FeS_2; losses were recorded in SiO_2, Na_2O, and Fe_2O_3. The gain in potash and alumina represents sericitization; that in lime, magnesia, ferrous oxide, and carbon dioxide represents carbonatization. The increase in FeS_2 represents the dissemination of pyrite through the wall rock. These results indicate that the ore-depositing solutions were alkaline in character, at least so far as the ores of the South ore zone at the MacLeod-Cockshutt mine are concerned. The answer to the question as to whether the solutions were acid or alkaline at greater depths must await further developments of the area.

Temperature. A method for distinguishing between alpha and beta quartz has been developed by V. B. Meen, who applying it to specimens of tourmalinized vein quartz from the Little Long Lac area, found that three specimens showed low-temperature, and three showed high-temperature, characteristics.[30] A specimen of quartz with tourmaline and gold, from the same region, showed high-temperature characteristics. Lindgren[31] has expressed the opinion that, in mesothermal deposits, there are only rare exceptions from the sequence, pyrite preceding arsenopyrite. Bandy[32] has recently developed a "normal sequence" theory. In his general paragenesis of hypothermal deposits, arsenopyrite crystallizes prior to pyrite.

[28] Ibid., p. 31.

[29] Morrow, H. F.: Op. cit., pp. 27–31.

[30] Meen, V. B.: The temperature of formation of quartz and some associated minerals. Toronto Univ. Studies, Geol. Ser., 38: 62, 1935.

[31] Lindgren, Waldemar: Mineral Deposits. 4th ed. rev. McGraw-Hill Book Co., Inc., New York. 1933. P. 544.

[32] Bandy, M. C.: A theory of mineral sequence in hypogene ore deposits. ECON. GEOL., 38: 556, 1940.

In the present study, the preponderance of the sequence arsenopyrite before pyrite, especially when considered in conjunction with Meen's results, indicates that the ore deposits may be allocated to Lindgren's hypothermal type. The occurrence of tellurides and the presence of galena and stibnite, however, indicate lower temperatures. It is possible, then, that the ore deposits of the Little Long Lac area are most correctly placed in the upper hypothermal, or lower mesothermal, zone.

Relations of the Ores to Intrusives.

The occurrence of dikes and larger masses of intrusive rocks has been discussed in the section on the general geology of the region. There appears to be no relation between the large albitite porphyry pipe and the ores at Hard Rock and MacLeod-Cockshutt. The porphyry is considerably earlier than the ores, as indicated by the presence of ore masses in cracks and fissures in the porphyry. The molten rock had been intruded, solidified, and fractured before the advent of the ore-depositing solutions. In the four westernmost mines in the area, some of the ores have been found in sheared and fractured porphyry and diorite. The possibility that the ores are genetically related to the porphyry must, however, be kept in mind until evidence to the contrary is found. During a long period of rhythmic violent earth movements, small elongate masses might be intruded along major planes of fracture where rapid cooling could take place. Subsequent movements would fracture and shear parts of these masses which might then serve as favorable loci for the deposition of ore minerals from solutions representing a late phase of the original source magma of the porphyries. The same movements that fractured the rock might aid in the circulation of the ore solutions.

A second possible source of solutions is from the granite masses which lie to the north and south of the belt of mines. Gray granite and pegmatite masses occur six to ten miles south, pink granites six to four miles north of the belt. It is possible that the ore solutions are consanguine with one or other of these rock masses.

The synclinal structure of the region suggests little except that, unless the lower part has been removed by igneous material, a considerable thickness must yet be penetrated before the original Laurentian(?) or Keewatin(?) floor is reached. The fact that the ore deposits occur along the same general strike, that is, parallel to the trend of the country, suggests that the syncline is truncated at depth. The planes thus opened provided easy access of ore solutions, especially when controlled either by structure or lithology or a combination of the two. This is in accord with a statement by E. S. Moore [33] to the effect that "in the Precambrian areas the gold commonly has been formed from solutions rising upward along limbs of synclines."

ACKNOWLEDGMENTS.

The officers of the various mines who have co-operated with the writer are too numerous to mention individually; to all of them he is very deeply indebted. Mr. P. C. Benedict of Newmont Mining Corporation has devoted considerable time to suggestions concerning the westernmost mines; Mr. H. F. Morrow of MacLeod-Cockshutt has similarly helped with those of the eastern part. Mr. H. L. Banting collected several suites of specimens when the writer was forced to leave the field early. Dr. M. H. Haycock of the Mines Branch, Ottawa, and Professor J. Ellis Thomson of the University of Toronto kindly loaned numerous polished sections. Professor E. L. Bruce of Queen's University freely loaned copies of the two theses written by students at that University. Finally, to Professor E. S. Bastin of the University of Chicago, the writer owes most sincere thanks for his suggestions and timely encouragement throughout the progress of this research.

McMaster University,
Hamilton, Ontario,
November 17, 1942.

[33] Moore, E. S.: Genetic relations of gold deposits and igneous rocks in the Canadian Shield. Econ. Geol., 35: 134, 1940.

DISCUSSION AND COMMUNICATIONS

POST–MINE LEACHING OF GALENA AND MARMATITE AT BROKEN HILL.

Sir: In their description of the post-mine leaching of galena and marmatite at Broken Hill, Messrs. Garretty and Blanchard[1] find themselves unable to account satisfactorily for the fact that the more usual order of solubility of these two minerals is here reversed, and that the galena is leached more rapidly than the marmatite. An explanation of this somewhat unusual phenomenon is perhaps provided by the recent work of Garrels.[2]

Garrels showed that the presence of Cl′ ions in Pb–Zn solutions, in concentrations in excess of 0.1 N, rendered the zinc less soluble than the lead. It seems possible that Cl′ ions may be present in the underground waters of the North Broken Hill mine in sufficient concentration to cause such reversal in the relative solubility of the lead and zinc sulphides.

Thus the analysis of "water believed to be free from contamination by mine drainage" given by Messrs. Garretty and Blanchard (p. 386 of their paper) is as follows:

Total solids in solution	878 grains per gallon
Pb	nil grains per gallon
Zn	28 grains per gallon
Mn	20.6 grains per gallon
Fe	nil grains per gallon
Cl	164 grains per gallon
F	nil grains per gallon
SO_3	400 grains per gallon
CO_2	nil grains per gallon
pH value	6.4

[1] Garretty, M. D., and Blanchard, Roland: Post-mine leaching of galena and marmatite at Broken Hill. Econ. Geol. xxxvii: 365, 1942.

[2] Garrels, R. M.: The Mississippi Valley type lead-zinc deposits and the problem of mineral zoning. Econ. Geol. xxxvi: 729, 1941.

164 grains of Cl′ per gallon is equivalent to 2.3394 grains of Cl′ per liter, which is equivalent to 0.066 N.

This concentration is approaching a value sufficient to cause a reversal of the relative solubility of zinc and lead salts; and it seems probable that there will be parts of the orebody where locally the Cl′ concentration will greatly exceed this figure. At such points the lead salts would be more soluble than the zinc salts, so that the galena would be leached more rapidly than the marmatite. With the dilution of such Cl′-rich waters with water containing less Cl′, the Cl′ concentration would fall below 0.1 N, and the lead would be reprecipitated, while the zinc would stay in solution, as for example, in the water analysis quoted.

The other point on which the authors speculate is the reason why the Northern Orebody in the mine has undergone greater leaching than the Southern Orebody. Since, however, the Northern Orebody actually overlies the Southern Orebody in any given vertical section, the ground waters must be drained from the Northern Orebody before the Southern Orebody. It seems possible that the greater post-mine leaching of the upper orebody is largely due to the fact that surface waters, in general, reach it first, before they are (*a*) saturated with dissolved minerals, and (*b*) neutralized by the carbonate gangue of the upper or northern orebody.

F. L. Stillwell,
A. B. Edwards.

Melbourne, Australia,
January, 1943.

REVIEWS*

Geology of the Appalachian Valley in Virginia. By CHARLES BUTTS. Part I—Geologic Text and Illustrations. Pp. 568; Pls. 63; Figs. 10. Part II—Fossil Plates and Explanations, Pls. 72. Virginia Geol. Surv., Bull. 52, Charlottesville. Part I, 1940; Part II, 1941. Price, Pts. I and II, $1.50; Pt. I not sold separately; Pt. II, fifty cents.

This excellent work, although based on ten field seasons of study in Virginia, is in a larger sense the result of almost a lifetime of field research by the author in the Appalachian Valley from New York state to Alabama. Many of the conclusions and interpretations of geologic problems in Virginia have been attained as much from knowledge gained elsewhere in the Valley as in Virginia, and the author's wide acquaintance with other portions of the Appalachian Province has made possible the solution of many problems of stratigraphy and correlation which hardly could have been solved from studies in Virginia alone. The special method of work consisted of making numerous traverses across the Valley throughout its length of 400 miles in Virginia; along these traverses many sections were studied in detail and extensive collections of fossils made.

This work is complementary to Virginia Geological Survey Bulletin 42, "Geologic Map of the Appalachian Valley of Virginia with Explanatory Text," published in 1933. The present work has been issued in two parts in order to avoid undue bulkiness and also to make the material of Part II separately available. It is well printed and excellently illustrated throughout with appropriately spaced photographs, maps, and sections.

Part I treats of the geologic relations, topography, drainage, stratigraphy, structure, and geologic history of the Appalachian Valley, or as also known, the Valley and Ridge province of Virginia. The first three of these topics are covered very briefly in the first 21 pages of the text but, although brief, are comprehensive enough to give an adequate background for the other topics. Under "Geologic Structure," pp. 436–468, the author first defines various structural terms and follows this with descriptions of the several faults, anticlines, synclines, and other structural features. The section on "Geologic History," pp. 469–514, summarizes the major events,

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

both physical and biological, in the geologic past of the area from the beginning of the Paleozoic era through the Pleistocene.

The major portion of Part I, pp. 22–435, deals with the Paleozoic stratigraphy. Each formation is discussed under a uniform set of headings: name, limits, character, distribution, thickness, and fossils and correlation. Although some workers in this region have advocated simplification of nomenclature by using the same name for a stratigraphic unit wherever it can be demonstrated to be the same, Dr. Butts has included all the valid names for each stratigraphic unit so that no confusion need arise. In so doing he has discussed equivalent units together as (1) Hampton-Harpers shale, (2) Lowville-Moccasin limestone, (3) Glen Dean limestone-Bluefield shale-Cove Creek limestone. The treatment of each formational unit is as complete as is consistent with a work of this magnitude. Many detailed sections, complete fossil lists, and illustrations of distinctive lithologic features are given in addition to the text discussions.

For most portions of the geologic column where there are differences of opinion as to the proper classification, Dr. Butts has given both sides of the question consideration and some of the assignments made in this work are not the ones which he personally would prefer, but they have been so made in order to harmonize with the policy of the Virginia Geological Survey, the U. S. Geological Survey, or the correlation subcommittees of the National Research Council, Division of Geology and Geography. Some of the more significant portions of the geologic column which have received such classification treatment are: (1) the section below the Erwin quartzite-Antietam sandstone, considered pre-Cambrian by some; (2) the Richmond group; and (3) the Keyser limestone. One exception to such unbiased treatment may be noted (p. 379). Dr. Butts in referring to the Mississippian in southern Illinois and western Kentucky still includes all of the Ohara limestone in the Ste. Genevieve formation despite the fact that most geologists working with these rocks believe that the "Ohara" is a composite unit, the upper portion of which is the same as the Renault formation of the Lower Chester of western Illinois, with only the lower portion (Levias limestone) a part of the Ste. Genevieve, as shown by A. H. Sutton and J. M. Weller.

Part II is composed of 72 plates of Paleozoic fossils comprising 1,979 figures, most of which are from original photographs by Charles E. Resser of the U. S. National Museum, 187 pages of text explaining the plates, and 11 pages of index. The figures illustrate 604 named and 116 unnamed species. Of the 604 named forms, 51 are only compared with described species and 15 others show affinities with definitely determined forms. One genus, 17 species, and two varieties are described as new. The description of each new form is given in the explanation of the plate

on which it is illustrated. Descriptions are very brief and are largely concerned with emphasizing the features which distinguish each new form from its nearest allies.

Dr. Butts is to be congratulated for the valuable contribution which he has made to our knowledge of the Paleozoic stratigraphy and paleontology of the Appalachian Valley in Virginia. The Virginia Geological Survey is likewise to be commended for making available this summation of the geologic investigations of the author over such a large area during such a length of time. It is a work which no student of Appalachian geology can afford to be without and one which should prove to be of inestimable value to all students of Paleozoic paleontology.

A. H. SUTTON

ALUMINUM ORE CO.,
ROSICLARE, ILL.

America At War. Edit. by SAMUEL VAN VALKENBURG. Pp. xiv + 296; Figs. 54. Prentice-Hall, Inc., New York. 1942. Price, $2.50.

In "America At War, A Geographical Analysis," one of the Prentice-Hall Geography Series, six geographers in search of a better world have set out to prove Spykman's statement that "geography is the most fundamental factor in the foreign policy of states because it is the most important." To do this they have not considered "place geography" but the importance of position, climate, land relief (particularly coastal), natural resources, population with its training and capacities, food supplies and potentials, distribution of mineral resources in the earth and sources of non-metallic raw materials. The claim that geographers long ago learned that isolation for any nation is impossible and that as students of world problems they know that some plan must be worked out for cooperation among the peoples inhabiting the earth permits inclusion of a final chapter on America and Peace. This all results in an interesting and stimulating book.

Ellsworth Huntington, considering the Quality of the People, remarks that if vigor alone were the determining factor, the white population of the United States would be more than a match for England, Germany and the Netherlands, and the high industrial productivity per worker points to a similar conclusion. His rather unique measurement of quality of the people leaves no doubt that the capacity of American people is great and his study provides statistical support that without the greatest natural resources in the world the quality of the people alone would enable us to defend ourselves, but in proportion to our opportunities we have by no means reached the final goal.

Wallace Atwood on Our Land and its Coastline stresses that self-appointed war strategists on coastal defense often overlook the fact that the total length of coastline of the United States and Alaska is one and one-half times the distance around the world at the equator. He reminds us that the great interior plains, bordered both east and west by formidable mountain barriers, is the most remarkable food-producing area of the world.

Samuel Van Valkenburg on Terrain and War Strategy makes some interesting topographic comparisons of ancient and modern battlefields, showing that modern military technique has changed the protective value of natural barriers. The most interesting of these he calls Thermopylæ 480 B.C. and 1941 A.D.

Van Valkenburg also considers the Climatic Factor in timing campaigns, taking advantage of bad weather conditions as well as good.

W. E. Ekblaw in Foods for Defense, summarizing food requirements, procurement, and producing sections, concludes that "the country as a whole is abundantly supplied with food to yield adequacy, variety, quality, and balance of diet for the strength and health necessary to sustain morale, maintain a high standard of productive efficiency and win the war, but there are regions of local insufficiency of food which might become critically vulnerable for defense should our transport system prove inadequate."

In Industrial Capacity and Supplies of Raw Materials, Clarence F. Jones, taking account of all raw materials, manufacturing capacity and man power, proves that the United Nations, not including the resources of the Philippines, the Netherlands East Indies, Malaya, lower Burma and eastern China, are still in a far better situation to equip for and wage a long war than are the Axis Powers. And, because of our extraordinarily favorable position, "whether we like it or not the burden of the conflict rests heavily on the shoulders of Uncle Sam."

Earl B. Shaw takes up United States Atlantic and Pacific Defense. He devotes considerable attention to the recently acquired Atlantic bases and to Hawaii and Alaska and re-deplores that Guam, Wake and the Philippines were not strongly fortified long ago.

Van Valkenburg on America and Peace modestly says that "planning of a postwar world is above all a geographical problem." After sketching an Axis-dominated world, he suggests four principles for post-war world reconstruction, elaborating the recently publicized eight large economic blocs.

E. M. W.

Handbook for Prospectors and Operators of Small Mines, 4th Edit. By M. W. VON BERNEWITZ, Rev. by H. C. CHELLSON. Pp. 547; Figs. 161. McGraw-Hill Book Co., New York, 1943. Price, $4.00.

In this volume H. C. Chellson, Editor of *Mining Congress Journal,* has edited the material prepared by the late M. W. von Bernewitz for the 4th edition of his popular handbook. In Part I the author has included details of a practical nature for the prospector living in the field, and has expanded (to a full chapter) information pertaining to mining law. Part II contains chapters on mineralogy, elementary geology, and the basic principles of ore occurrence and observation as well as data to aid in sampling, assaying and making field tests of a deposit. Separate chapters are devoted to developing and equipping a prospect and markets and prices. Two thorough chapters on metallic minerals and nonmetallic minerals make up Part III. In Parts IV and V Chellson has brought up to date and discussed ore dressing, equipment and metal prices and ore marketing. A 40-page glossary of geologic and mining terms closes the text. "All this material is designed to aid the prospector and small mine operator in his war effort, as well as post war mining." Important for more than its timeliness, this book should continue as an invaluable "partner" for those for whom it was intended.

R. E. D.

Dolomites and Limestones of Western Ohio. By WILBER STOUT. Pp. xiv + 468; Geol. map. Ohio. Geol. Surv., 4th Ser., Bull. 42, Columbus, 1941.

The State Geologist of Ohio here presents a comprehensive and complete account of the dolomites and limestones of western Ohio. A consideration of the origin of the rocks and the physiographic and structural conditions maintaining is followed by a list and description of each formation. This classification is based on the rock systems present in the area and covers geologic time from pre-Cambrian through Devonian. Individual deposits are discussed according to counties and each of the numerous analyses of samples are intended as a "type" analysis for a district. Chapter IV covers the utilization of the dolomites and limestones of the region and is concluded with a directory of operators in western Ohio including approximate locations of the quarries, the formations worked and chief materials produced. Quarrying methods, manufacturing processes, and marketing conditions are not discussed.

R. E. D.

BOOKS RECEIVED.

RALPH E. DIGMAN.

U. S. Geol. Surv., Washington, 1942.

BULLETINS.

926–C. Occurrences of Molybdenum Minerals in Alaska. PHILIP S. SMITH. Pp. 48; Pl. 1. Price, 15 cents.

928–A. Stratigraphy, Structure, and Mineralization in the Beaver-Tarryall Area, Park County, Colo. Q. D. SINGEWALD. Pp. 43; Figs. 2; Pls. 5. Price, 15 cents.

929. Geology and Ore Deposits of the Chichagof Mining District, Alaska. J. C. REED AND R. R. COATS. Pp. 147; Figs. 24; Pls. 33. Price, $3.35.

930–A & B. Spirit Leveling in Illinois, 1896–1941. Pt. 1, Southern Illinois, Pt. 2, West-Central Illinois. Pp. 918; Figs. 115; Pls. 10. Price, 65 cents (part 1) and 60 cents (part 2).

931–H. Tin and Tungsten Deposits at Silver Hill, Spokane County, Washington. LINCOLN R. PAGE. Pp. 24; Figs. 4; Pls. 5. Price, 30 cents.

931–K. The Wild Horse Quicksilver District, Lander County, Nevada. C. H. DANE AND C. P. ROSS. Pp. 19; Figs. 2; Pls. 3. Price, 25 cents.

931–R. Manganese Resources of the Olympic Peninsula, Washington. CHARLES F. PARK. Pp. 22; Figs. 9; Pls. 7. Price, 35 cents.

931–S. Manganese Deposits in the Paymaster Mining District, Imperial County, California. J. B. HADLEY. Pp. 25; Figs. 5; Pls. 3. Price, 30 cents.

932–D. Geophysical Abstracts 107. October–December, 1941. W. AYVAZOGLOU (Complied). Pp. 44. Price, 10 cents.

935–A. Chrome Resources of Cuba. T. P. THAYER. Pp. 72; Figs. 6; Pls. 20. Price, $1.00.

935–B. Manganese Deposits of Cuba. CHARLES F. PARK, JR. Pp. 22; Figs. 3; Pls. 4. Price, 10 cents.

936–A. Muscovite in the Spruce Pine District, North Carolina. T. L. KESLER AND J. C. OLSON. Pp. 36; Fig. 1; Pl. 1. Price, 35 cents.

936–B. Tungsten Deposits of the Nightingale District, Pershing County, Nevada. WARD C. SMITH AND PHILIP W. GUILD. Pp. 18; Fig. 1; Pls. 4. Price, 40 cents.

936–C. Topaz Deposits near the Brewer Mine, Chesterfield County, South Carolina. CARL FRIES, JR. Pp. 17; Fig. 1; Pls. 4. Price, 30 cents.

936–D. Chromite and Quicksilver Deposits of the Del Puerto Area, Stanislaus County, Calif. H. E. HAWKES, JR., AND OTHERS. Pp. 31; Figs. 10; Pls. 2. Price, 30 cents.

936–E. Manganese Deposits of Cedar Creek Valley, Frederick and Shenandoah Counties, Virginia. W. H. MONROE. Pp. 28; Pls. 4. Price, 35 cents.

936–F. Quicksilver Deposits of the Parkfield District, Calif. E. H. BAILEY. Pp. 25; Fig. 1; Pls. 4. Price, 35 cents.

936–G. Chromite Deposits of Red Bluff Bay and Vicinity, Baranof Island, Alaska. P. W. GUILD AND J. R. BALSLEY, JR. Pp. 14; Figs. 2; Pls. 2. Price, 20 cents.

936–H. Quicksilver Deposits Near the Little Missouri River, Pike County, Arkansas. DAVID GALLAGHER. Pp. 29; Figs. 5; Pls. 13. Price, 55 cents.

936–I. Nickel-Copper Deposits on the West Coast of Chichagof Island, Alaska. W. T. PECORA. Pp. 20; Figs. 5; Pls. 2. Price, 20 cents.

936–K. Tin Deposits of Irish Creek, Virginia. A. H. KASCHMANN AND OTHERS. Pp. 25; Figs. 2; Pls. 2. Price, 10 cents.

936–M. Nickel-Copper Deposit at Snipe Bay, Baranof Island, Alaska. J. C. REED AND G. O. GATES. Pp. 10; Figs. 2; Pl. 1. Price, 10 cents.

936–O. Nickel-Copper Deposit at Funter Bay, Admiralty Island, Alaska. JOHN C. REED. Pp. 11; Figs. 2; Pls. 2. Price, 15 cents.

939–A & B. Geophysical Abstracts 108. January–March and April–June 1942. W. AYVAZOGLOU (Compiled). Pp. 65. Price, 10 cents each.

WATER SUPPLY PAPERS.

889–A. Water Supply of the Dakota Sandstone in the Ellendale-Jamestown Area, North Dakota. L. K. WENZEL AND H. H. SAND. Pp. 81; Figs. 3; Pls. 3. Price, 50 cents.

890. Ground-Water Resources of the Williamette Valley, Oregon. A. M. PIPER. Pp. 194; Figs. 3; Pls. 10. Price, 45 cents.

891. Surface Water Supply of the United States, 1940. Pt. 1, North Atlantic Stope Basins. G. L. PARKER AND OTHERS. Pp. ix + 567; Pl. 1. Price, 70 cents.

892. Surface Water Supply of the United States, 1940. Pt. 2, South Atlantic Slope and Eastern Gulf of Mexico Basins. G. L. PARKER AND OTHERS. Pp. viii + 441; Pl. 1. Price, 50 cents.

893. Surface Water Supply of the United States, 1940. Pt. 3, Ohio River Basin. G. L. PARKER AND OTHERS. Pp. ix + 662; Pl. 1. Price, $1.00.

894. Surface Water Supply of the United States, 1940. Pt. 4, St. Lawrence River Basin. G. L. PARKER AND OTHERS. Pp. v + 213 Price, 25 cents.

895. Surface Water Supply of the United States, 1940. Pt. 5, Hudson Bay and Upper Mississippi River Basins. G. L. PARKER AND OTHERS. Pp. vii + 340; Pl. 1. Price, 40 cents.

896. Surface Water Supply of the United States, 1940. Pt. 6, Missouri River Basin. G. L. PARKER AND OTHERS. Pp. viii + 457. Pl. 1. Price, 50 cents.

898. Surface Water Supply of the United States, 1940. Pt. 8, Western Gulf of Mexico Basins. G. L. PARKER AND OTHERS. Pp. viii + 426; Pl. 1. Price, 65 cents.

905. Surface Water Supply of Hawaii, July 1, 1939 to June 30, 1940. G. L. PARKER AND M. H. CARSON. Pp. iv + 136. Price, 20 cents.

908. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1940. Pt. 3, North-Central States. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 288; Figs. 7. Price, 30 cents.

911. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1940. Pt. 6, Southwestern States and Territory of Hawaii. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 240; Figs. 15. Price, 30 cents.

927. Surface Water Supply of the United States, 1941. Pt. 7, Lower Mississippi River Basin. G. L. PARKER AND OTHERS. Pp. vi + 355; Pl. 1. Price, 40 cents.

929. Surface Water Supply of the United States, 1941. Pt. 9, Colorado River Basin. G. L. PARKER AND OTHERS. Pp. vi + 311; Pl. 1. Price, 35 cents.

930. Surface Water Supply of the United States, 1941 Pt. 10, The Great Basin. G. L. PARKER AND OTHERS. Pp. iv + 123; Pl. 1. Price, 25 cents.

931. Surface Water Supply of the United States, 1941. Pt. 11, Pacific Slope Basins in California. G. L. PARKER AND OTHERS. Pp. viii + 417; Pl. 1. Price, 55 cents.

932. Surface Water Supply of the United States, 1941. Pt. 12, Pacific Slope Basins in Washington and Upper Columbia River Basin. G. L. PARKER AND OTHERS. Pp. v + 214; Pl. 1. Price, 25 cents.

933. Surface Water Supply of the United States, 1941. Pt. 13, Snake River Basin. G. L. PARKER AND OTHERS. Pp. vi + 246; Pl. 1. Price, 30 cents.

934. Surface Water Supply of the United States, 1941. Pt. 14, Pacific Slope Basins in Oregon and Lower Columbia River Basin. G. L. PARKER AND OTHERS. Pp. vi + 229; Pl. 1. Price, 35 cents.

940. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1941. Pt. 5, Northwestern States. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 172; Figs. 6. Price, 25 cents.

U. S. Bureau of Mines, Washington, 1942.

Bull. 450. Metal- and Nonmetal-mine Accidents in the U. S., 1940, (Excluding Coal Mines). W. W. ADAMS AND M. E. KOLHOS. Pp. 51. Price, 10 cents.

Tech. Pap. 641. Analysis of Illinois Coals. Pp. 245; Figs. 11. Price, 30 cents.

Tech. Pap. 642. Hydrogenation and Liquefaction of Coal. C. H. FISHER AND OTHERS. Pp. 162; Figs. 52. Price, 25 cents.

Tech. Pap. 644. Carbonizing Properties and Petrographic Composition of Bakerstown-Bed Coal. J. D. DAVIS AND OTHERS. Pp. 45; Figs. 24. Price, 15 cents.

Tech. Pap. 645 (Supplement of 590). Analyses of Pennsylvanian Bituminous Coals. N. H. SNYDER AND R. J. SWINGLE. Pp. 19. Price, 10 cents.

Tech. Pap. 646. Hydrogenation and Liquefaction of Coal. L. L. HIRST AND OTHERS. Pp. 27; Figs. 19. Price, 10 cents.

SOCIETY OF ECONOMIC GEOLOGISTS

WILLIAM SHIRLEY BAYLEY.

1861–1943.

William Shirley Bayley, geologist, petrologist, mineralogist, and inspiring teacher, died on February 13, 1943, in Glen Rock, New Jersey, at the home of his daughter, Elizabeth Gillen. He continued his work at the University of Illinois as business editor of ECONOMIC GEOLOGY until November, 1942, when failing strength led him to join his daughter where he spent his last months happily enjoying the company of her family. He was buried in Urbana, Illinois, where he had made his home for 35 years.

Dr. Bayley was born November 10, 1861, in Baltimore, Maryland. He entered Johns Hopkins University at a time when he had the exceptional privilege of studying under two of America's most inspiring teachers, Ira Remsen in chemistry, and George H. Williams, who introduced petrography into American geology. Thus was laid the basis for his keen appreciation of the value of chemistry, petrology, and mineralogy in the solution of problems in geology. He received his A.B. degree in 1883, and the Ph.D. degree also from Johns Hopkins University in 1886.

The interest in petrologic problems, through his close association with Williams, led Dr. Bayley to commence a study of the rocks of Pigeon Point, Minnesota, in the summer of 1885. These studies led to the publication of U. S. Geological Survey Bulletin 109, a pioneer study of the origin of an igneous rock. This initiated his work in the Lake Superior region which was destined to be his major geologic interest for many years. In 1886 he joined a field party of the U. S. Geological Survey, first as a volunteer assistant. The following year he began his work on the iron-bearing districts of the region and his associations with R. D. Irving, Van Hise, Smyth, Clements, and Leith. He had a part in the U. S. Geological Survey work in all the iron-bearing districts of the region, was author of the Monograph on the Menomonie district, and joint author with Van Hise and Smyth on those on the Marquette and Crystal Falls districts; he also did much of the field work on the Vermilion district. In addition, many scientific papers on geology and petrography resulted from his studies in the Lake Superior region.

Later, he turned his attention to the crystalline rocks of the Highlands of New Jersey, and his previous work with iron formations led to a de-

tailed study of the New Jersey iron mines. During the first world war he made a study of the magnetic iron ores, the brown iron ores, and the titaniferous iron ores of North Carolina, and in addition published many scientific papers on ore deposits, igneous rocks, and the high-grade clay of North Carolina. In 1927, he made a detailed study of the Tate Quadrangle for the Georgia State Geological Survey. His work as a teacher led to the preparation of textbooks on mineralogy, crystallography, petrology, and economic geology.

Dr. Bayley's major interests were economic geology, mineralogy, crystallography, and petrology, but his own broad training led him to insist that his students be broadly grounded in the fundamental sciences. He passed these interests on not only to his students of geology, but also to those in chemistry and in particular to ceramists. The many ceramic engineers who make effective use of petrologic methods in the ceramic industry owe much to his teaching. Dr. Bayley has contributed much to geology and to geologists by his many papers and books, by his long service to this journal, and as a member and officer of the Society of Economic Geologists and other scientific societies; but added to this was the kindly helpfulness he gave to all who knew him, to all those who had the privilege of working with him and knowing his loyal friendship.

C. S. Ross.

April 15, 1943.

MILLARD KING SHALER.

1880–1942.

Millard King Shaler graduated from the University of Kansas in 1901 and three years later received a B.S. in Mining Engineering. He thereafter spent four years with the United States Geological Survey.

From 1907 to the date of his passing on at Capetown, December 11, 1942, he was associated with the Société Internationale Forestière et Minière du Congo, first as engineer, later as manager and director. To this company the United Nations look for two-thirds of their industrial diamonds and an appreciable percentage of their tin ore.

Shortly after the first World War broke out, Shaler was asked by the Belgian authorities to purchase in London a large amount of food to keep the Belgian civil population from starving. As a result of his trip to London, Herbert Hoover's Commission for Relief in Belgium was formed. Shaler became one of the secretaries of the organization, the other being our good friend, H. Foster Bain. He thereafter was prominent in the counsels of that organization and its successor, the Belgian American Educational Foundation, Inc., and its sister organizations.

Shaler was highly honored by his European associates by being made a Doctor Honoris Causa by both the University of Louvain and that of Brussels; a Commander of the Order of Leopold, an Officer of the Royal Order of the Lion, and an Officer of the Legion of Honour. He was a member of the Society of Economic Geologists, the A. I. M. E., of the Mining and Metallurgical Society of America, Geological Society of America, the American Chemical Society, and the Société Geologique de Belgique.

Shaler was not only an engineer and administrator of ability, but his friendly and lovable character made him a host of friends.

S. H. BALL.

February 25, 1943.

RICHARD CARLYSLE CADY.

1908–1943.

Major Richard Carlysle Cady died January 15, 1943, at the age of 35 years, as a result of accidental injuries received on January 3, while on overseas duty in the United States Army. He had been engaged for about a year in locating well sites to develop water supplies for military establishments in Africa and Asia.

Major Cady was born in Cortland, N. Y., graduated from Colgate University, and did post-graduate work in Colgate and Harvard. He was appointed in the Geological Survey, United States Department of the Interior, in 1930, and from 1931 until he began his African work, he served continuously in the Ground Water Division of the Survey. He is the author of a number of papers relating to geology, hydrology, and meteorology. It is believed that when his two comprehensive reports on western Nebraska are published it will become evident that he has made a notable contribution to the geomorphology, Tertiary and Pleistocene geology, and hydrology of the Great Plains. Thus, his utimely death is a serious loss to these fields of science.

Dick Cady enjoyed life and lived it fully, and he had a well developed sense of humor. He had many friends and spent much time with them, and yet he found time to read widely, enjoy good music, live a very happy family life, and write creditable poetry. He was a philosopher and idealist. His thinking was characterized by broad interests and perspective, and by deep sympathy with the underprivileged.

The meager information that has penetrated the veil of secrecy indicates that his overseas work was successful and has had valuable military results. This is also indicated by his promotion from the rank of Captain to that of Major. His entrance into the Army for the dangerous work in

Africa was entirely in accordance with his enthusiastic and patriotic desire to serve the country in this critical time by application of the special skill that he acquired in his years of ground-water investigation. Since his death his wife has remarked that even if he had known the outcome, he would have gone just the same.

O. E. MEINZER.

March 4, 1943.

DAVID GROSH THOMPSON.

1888–1943.

David Grosh Thompson was born in Lockland, Ohio, May 12, 1888, and died in his home in Washington, D. C., February 19, 1943. He was graduated from Northwestern University, received a Master's Degree from the University of Illinois, and also took graduate work in Chicago and Johns Hopkins Universities. He served on the geological surveys of Illinois and Maryland, and was an instructor in Lehigh University and Goucher College. From 1917, until his death, he served in the Ground Water Division of the U. S. Geological Survey. At the time of his death he was a member of the Council of the Society of Economic Geologists, serving on the Program and nominating committees. In 1922, he was married to Frances E. Goodrich. He is survived by her and by their two sons.

In the 25 years of his service in the Geological Survey, he made many valuable contributions to the geology and hydrology of the United States, and he deserves much of the credit for the success of the Ground Water Division and the development of ground water methods. His first work in the Geological Survey was his watering-place survey of the Mohave Desert Region, which resulted in his comprehensive and well known water-supply paper on the geography, geology, and hydrology of that region. His greatest achievement was probably the vast amount of extremely valuable work which he did in the present emergency on the water supplies for military and naval establishments and war industries.

Mr. Thompson had the research type of mind. He had a keen interest in a wide range of scientific problems. His investigations were deep and thorough. He was a man of sterling character; clean, upright, wholly without guile; devoted and kind to his family; considerate and unselfish in all his human relations. Conspicuous was his profound sense of responsibility toward all duties which he assumed. He was esteemed and loved by a wide circle of friends and professional associates.

O. E. MEINZER.

March, 1943.

SCIENTIFIC NOTES AND NEWS

The following letter has been received by the editor from Ernest E. Fairbanks, Hyattsville, Maryland:

Dear Sir: The geologic map appearing on page 27 of the January–February, 1943 issue of ECONOMIC GEOLOGY indicates an area of norite near Dracut, Mass., stated to occupy "about 27 square miles." According to the map's scale this area is nearer 9 square miles. The source of this error is a map published by me in the Proceedings of the Boston Society of Natural History, Vol. 38, No. 8, 1927, p. 399. Although the original map was reduced to meet page requirements, its scale was not corrected. The estimate of about 27 square miles was published in this original paper. While I am pleased to find my hypothetical map prepared as a student in 1923 receiving this attention, I would have appreciated credit for same.

V. M. GOLDSCHMIDT of the University of Ohio, distinguished for his work in mineralogy, petrology and geochemistry, early in March reached England safely from Norway.

D. H. MCLAUGHLIN, dean of the college of engineering at the University of California, was recently elected a director of the Homestake Mining Co. and an honorary member of the Sociedad Geológica del Perú.

H. G. MOULTON, president of the A. I. M. E. in 1940, was commissioned Lieutenant Colonel in the Army early in March. He is connected with the Headquarters Services of Supply in Washington.

G. O. SMITH, former head of the U. S. Geological Survey, was honored on his 72nd birthday, February 22, by the Rotary Club of Skowhegan, Maine.

A. C. SWINNERTON, head of the department of geology at Antioch College, is on leave of absence as consultant to the Research and Development Division of the Signal Corps in Washington.

PETER JORALEMON, who graduated in December from the Yale department of geology, is now connected with the Metals section of the U. S. Geological Survey in Washington.

K. F. MATHER, professor of geology at Harvard University, is chairman of a National Wartime Conference of the professions, arts, sciences

and white-collar fields to be held at the Hotel Commodore in New York City on May 8th and 9th.

A. L. Du Toit was elected a fellow of the Royal Society, London on March 18th, in recognition of his contributions to the geology and petrology of South Africa, particularly his work on the Karoo System.

C. H. Behre, Jr., professor of economic geology at Columbia University, spoke before the Royal Canadian Institute of Toronto in March on "The Mineral Resources of Europe."

L. C. Graton, Sturgis Hooper professor of geology at Harvard University, left by air for Mexico on April 8 to visit the new volcano and observe its gases and heat during eruption.

J. E. Tobey, managing director of the coal bureau of the Upper Monongahela Valley Association, announces that the offices have been moved to 122 E. 42nd St., New York City.